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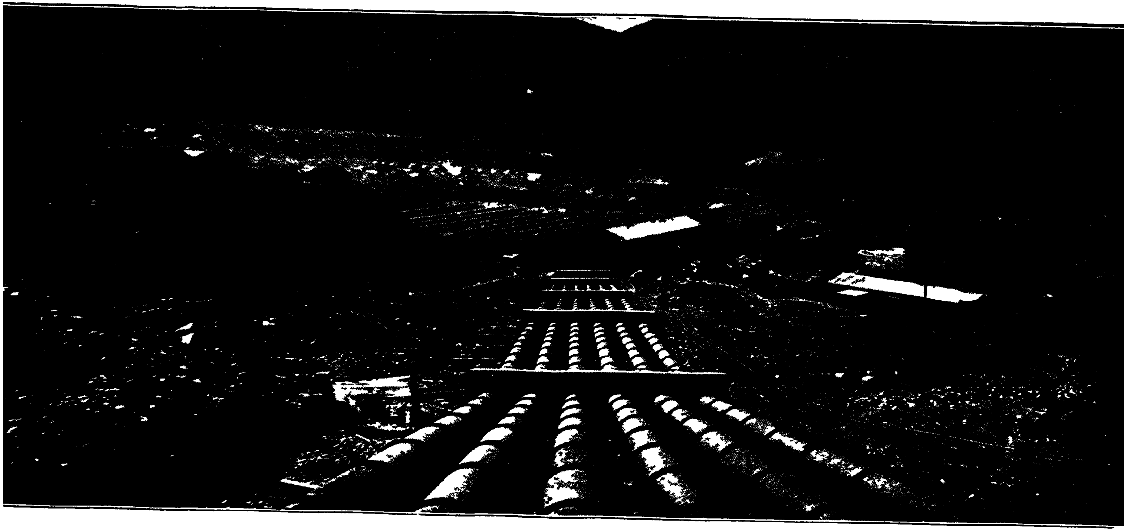

FIG. 1

AN EXTENSIVE ALUMINIUM REDUCTION WORKS IN SCOTLAND

Fronti.

PITMAN'S COMMON COMMODITIES
AND INDUSTRIES

ALUMINIUM

ITS MANUFACTURE,
MANIPULATION
AND MARKETING

BY

GEORGE MORTIMER,
M INST. MET

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PREFACE

In this little volume the author has aimed at an easy analysis of the processes through which aluminium passes in its metamorphosis from "common field mud" to the light, silvery metal familiar to the reader. Comparatively little literature on the subject exists at the present time, and, while its treatment here is necessarily limited in scope, it is hoped that the information afforded may be of interest and possibly of utility. To further this end, chapters have been included on working with aluminium and on its varied applications in industry, written, be it said, neither for the specialist nor the advanced student, but rather for such as desire a general working knowledge of the metal, and for the assistance of those who, caught in the wake of progress, find it incumbent upon them to alter their methods and standards to the newer metal.

The student is referred to the writings of Professor J. W. Richards, from whose standard work the author has gleaned much of his information on the historical aspect, and also to a small book, *The Manufacture of Aluminium*, by J. T. Pattison, which contains a useful series of analyses.

The author wishes to acknowledge his indebtedness to—

The Metal Industry;
The Mining Journal (London);
The Electrical Review (London);
Metallurgical and Chemical Engineering (New York);
Engineering (London);
Messrs. Thermit, Ltd.;
Messrs. the Manchester Armature Repair Co., Ltd.;

And finally to the staff of the British Aluminium Company, Ltd., for a mine of information on the applications of the metal, for the loan of blocks, and for much courteously rendered assistance in the latter part of the book.

LONDON.
October, 1919.

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ALUMINIUM

PART I

FROM CLAY TO CONSUMER

CHAPTER I

> **" Had I been so fortunate as to obtain the metallic substance I was in search of, I should have proposed for it the name ALUMIUM."—*Davy*, 1808.**

The history of the discovery and development of the metal referred to by Davy, now known as aluminium, is comparatively recent and has scarcely crystallised out into coherent narrative. It is true that the name itself, derived from the Latin *alumen,* bears the stamp of a certain antiquity. Coloured salts called " alumen " are referred to at length in the writings of Pliny, in whose *Natural History* may be found full descriptions of the varied forms used about that period in the preparation of certain dyes. Why they were named alumen is not clear, unless, as suggested by Professor Richardson in his classic volume, the word is a colloquialism having a bearing on the light effect given by the colours of the dyes, much in the same sense as the term " illuminated address " is used at the present day.

The alumens described by Pliny, however, are difficult to identify with any pure salts of aluminium: the name seems to have been applied to most salts having an astringent taste, and those used in the art of dyeing were possibly of the nature of impure sulphates of iron or aluminium, or a mixture of both. It is not until several centuries have elapsed that we read of the working of a very pure form of alumen at Rocca, this form gradually becoming known to merchants as "rock alum," and to ourselves to-day as *alum*—a pure sulphate of aluminium with sulphate of potassium.

The history of the metal itself transfers us at once into a more modern era; so near in point of time that it is not easy to gain a perspective which is unobscured by a confusion of detail. An analysis of outstanding features, however, will show that the story of the metal passed through four well-defined phases—

(*a*) The inception of the idea that the base of alum was an individual substance, probably of an earthy nature.

(*b*) The growth of the conviction that this base was of a metallic nature, resulting in a search which culminated in its successful isolation.

(*c*) Production of the new metal on a commercial scale, mainly along chemical lines.

(*d*) Renewed enterprise in electrolytic processes, made possible by developments in dynamo design, finally ensure the success of aluminium as a commercial metal.

The first phase commences in history with a statement by Stahl in 1702 to the effect that the base of alum was substantially of a chalky nature, and this hypothesis received support from Hoffmann in 1722, who expressed his opinion that the unknown base was a definite, individual substance, of the nature of an alkaline earth. This line of thought predominated for fully half a century, and it was not until the year 1760 that Baron, in his *Memoires de l'Academie Royale*, advanced the theory that the unknown substance was metallic in nature and had few properties in common with the known earths. "I think it not too venturesome to predict," he writes, "that a day will come when the metallic nature of the base of alum will be incontestably proven."

From this date onwards the history enters on the second phase, and the search for aluminium as a metal was fairly started. The period 1760–1807 is marked by great activity among European chemists, but nothing of any great moment may be instanced until the latter date, when Davy, with the aid of his great battery, succeeded in isolating the alkaline metals, potassium and sodium, and unknowingly laid the foundation-stone upon which are built the electrolytic enterprises of the present day. This success caused some stir. Davy turned his attention to the isolation of aluminium, and in 1809, with a more powerful battery, he attempted the decomposition of alumina by raising an iron wire to a high temperature in contact with the oxide. He obtained evidence of the formation of an alloy whiter and more brittle than iron, and although he was unable to isolate the foreign metal, he did establish the fact that alumina may be decomposed by a high temperature and its base alloyed with iron. This fact is worth noting in view of the success of the Cowles' process for the production of aluminium alloys, eighty years later. The metal itself, however, continued to defy all efforts at its isolation, and we have little of importance on record until 1824.

In this year H. C. Oersted, a Swede, working on purely chemical lines, heated aluminium chloride with potassium amalgam, in the hope that the chlorine would combine with the potassium and set free the aluminium. The experiment was unsuccessful, and is quoted as an instance of the narrow margin by which some of the early workers missed their objective. For the cause of the failure was merely the presence of the mercury in the amalgam, and it was only three years later that Frederick Wöhler, Professor of Chemistry at Göttingen University, modified Oersted's experiment by using pure potassium, and succeeded where the Swedish chemist had failed.

The aluminium obtained by Wöhler in 1827 was not chemically pure: it contained small quantities of potassium and of platinum from the crucible, and it took the form of a grey powder. But even in this form a number of its chemical properties could be determined: the isolation of the metal was an accomplished fact, and the second phase of its history came to a close.

From now onwards we are concerned with the development of the metal from a scientific novelty into an important factor in modern industry.

In 1845 Wöhler followed up his earlier experiments by passing a vapour of aluminium chloride over potassium. The chloride was reduced and the first metallic globules of aluminium resulted. The metal thus obtained, however, was still impure, and it is to Deville that we are indebted not only for the first successful isolation of pure metal, but also for a process which placed its production within the realm of commerce.

H. St. Claire Deville was at that time (1854) Professor of Chemistry at the École Normale, Paris, and was engaged on research work in the direction of the protoxide and other proto salts of aluminium. Unknowingly he repeated Wöhler's experiment, noted the reduction of the chloride and the formation of globules of a silvery metal, and at once abandoned his original pursuit to concentrate on the production of aluminium. In this he was financially assisted by the Academy and by Napoleon III, and after prolonged and clever research "without responsibility on my part, and in consequence with the tranquillity and repose of mind so often wanting in the investigator," he placed the production of aluminium on a basis that brought the price down from £23 to 28s. per lb.

Deville's first process was, as described, the reduction of the chloride by means of potassium. The latter metal, however, was a costly item, dangerous to handle, and gave a depressingly low yield of metal on its initial outlay. We, therefore, find him early in 1854 turning his attention to electricity, the possibilities of which had already been demonstrated by Bunsen in his decomposition of the chloride of magnesium.

Deville succeeded in producing pure aluminium by reduction of its chloride in the electric arc, and there is little doubt that, had our modern machinery been at his disposal, the development of the aluminium industry would have been advanced by many decades. The sole source of electrical power at that time was the primary cell, and the consumption of zinc placed the process beyond the pale of commercial enterprise. Returning to his alkalis, Deville investigated the claims of sodium in place of potassium as a reducing agent, and until 1858 was patiently engaged in improving methods of extracting this metal. His admirable work in this side track brought the price of sodium down from £30 per lb. to 6s. per lb., and the price of aluminium came down in sympathy to about £1 per lb. In 1855 he had established a works at Javel for the production of aluminium by the reduction of its chloride by sodium:

$$AlCl_3 + 3\ Na = 3\ Na\ Cl + Al,$$

and with the excellent results achieved by his genius and unwearied zeal, the young industry began to give promise of healthy development.

This was the essential form of the Deville process, such modifications as appeared from time to time being chiefly in the direction of cheapening the production of sodium, and of the substitution of fluorides for the chloride. Notably in connection with the former, the genius of Castner in New York and of Webster in England brought the price of sodium down to 10d. per lb., and with regard to the latter, the use of cryolite in place of chloride, strongly advocated by K. Rose in 1855, was adopted by the Tissier Bros. in their works at Amfreville, near Rouen. The main drawback to the use of cryolite was found in the large percentage of silicon in the aluminium produced by this firm, approaching in some cases 4 per cent. Silicon is an highly undesirable impurity in aluminium, and this disability to produce a metal of high purity led to the abandonment of the process.

Other processes and modifications were patented and floated from time to time, desert growths of great promise or the reverse: patent records of the period are full of them, like seeds in a gourd, and as difficult of digestion. The fact remains that the Deville classic process held the field for thirty years, during which period some 100,000 lb. of the metal were placed on the market, and the price fell from 450s. to 20s. a pound.

The chemical processes died a natural death with the advance in design of electro-dynamic machinery, and this brings us to the fourth and final phase, which extends into the present day.

The sole factor which affected the industrial success of Bunsen's and Deville's experiments in electrometallurgy in 1854 was, as before stated, the prohibitive running cost of primary cells. From about 1880 onwards, however, the electrical world underwent revolutionary changes in the rapid development of the dynamo, and, as is well known, these changes brought in their wake a wealth of far-reaching effects in the ways and usages of mankind in general, and of the mechanical and metallurgical industries in particular.

The aluminium industry was no exception. In 1883 Grätzel patented in Germany a process providing for the electrolysis of aluminium salts while in a state of fusion, and although it failed, the patent is quoted as usefully indicating the trend of current thought. Three years later we find a patent by Dr. Kleiner of Zurich, almost identical with the above, excepting that Kleiner specified the use of cryolite, and provided for the initial fusion of the salt by the passage of the current, a point to be noted in the sequence of events. Neither of these processes came to anything, and indeed little was done in electrolytic production until the epoch-making invention of Charles Hall, of Oberlin, Ohio.

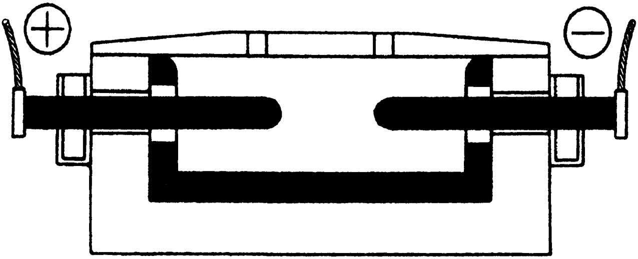

FIG. 2
DIAGRAM OF COWLES' FURNACE

The pith of Hall's patents, which were applied for in 1886, and finally granted in U.S.A. in 1889, lay in the fact that the fluorides in a molten condition will take into solution a considerable quantity of alumina—over 20 per cent. Once in solution at about 800° C. the

" bath " is amenable to electrolysis like any other liquid, and it was found that provided the applied tension did not exceed 6 volts, the alumina was split up into aluminium and oxygen, while the cryolite solvent remained unaffected.

The year 1886 saw two further electrical processes launched—the Cowles at Milton, in Staffordshire, and Hèroult at Neuhausen.

The Cowles' furnace (Fig. 2) consisted of a long oblong box of iron, heavily lined with carbon and packed loosely with powdered corundum. The latter is a pure oxide of aluminium, and for the purposes of the process it was mixed with charcoal and either iron or copper in a granulated state. Working horizontally or slightly inclined through each end of the furnace were the carbon electrodes, between which passed a current of 5,000 amperes at 60 volts. The process, consisting essentially in the reduction of alumina by carbon, does not appear to have been electrolytic in character, the current being utilised simply as a source of great heat. The author has produced alloys of aluminium and other metals by this process with the aid of a three-phase alternating supply. Reduction of the alumina, while avoiding volatilisation of the aluminium as it formed, was found to be practicable only in the presence of iron or copper or other metal of fairly high melting point, so that this firm specialised chiefly in alloys, which at that time had a ready market.

By 1892, however, the Hèroult-Hall process had made such strides that there was a good supply of pure metal at under 7s. per lb.; the Cowles' syndicate could not compete with this together with the growing inclination in the metal industry towards mixing its own alloys, and failed to maintain its position.

Hèroult's original conception as patented in France in 1887 was substantially identical with Hall's, but he does not appear to have developed his valuable asset until about 1890, when Hall's growing success in America began to attract general attention.

The Hèroult process as at first worked at Neuhausen may be almost described as a cross between the Hall and the Cowles. His furnace consisted of an iron container lined with carbon blocks forming the cathode as in Hall's specification (Fig. 3). A bundle of carbon anodes hung vertically into the crucible thus formed, and dipped into the " bath " of alumina fused by the heat of the arc. The current specified was 400 amperes at 20–25 volts—far in excess of the tension used by Hall. The alumina was split up into oxygen and aluminium, the latter settling on the cathode bottom of the furnace. But as in the Cowles' process, the heat generated was sufficient to volatilise the aluminium, and this was therefore caught and alloyed with a layer of molten copper at the bottom as it formed. The layer of other metal being essential to the success of the process, the Neuhausen firm produced only alloys for some years, in which line they built up a satisfactory business. Later on, however, with the growing demand for pure metal, modifications crept in until at the present day the process is difficult to distinguish from Hall's, and the Hall-Hèroult process for the electrolytic extraction of aluminium is now wholly responsible for the world's great and growing output of the metal.

The process is dealt with more fully in a later chapter, but as a conclusion to this brief history, it may not be out of place to mention some of the more important works of the pioneer firms now using it.

In the States, the Aluminium Company of America, formerly the Pittsburg Reduction Co., Ltd., were the first to use the Hall method, and now own large reduction works at Massena Springs, at Niagara, and New Kensington, while on the Continent the Aluminium Industrie Ges., the development of Hèroult's works at Neuhausen, has expanded into an important concern with works at Neuhausen, Rheingelden, and Bergheim, near Cologne.

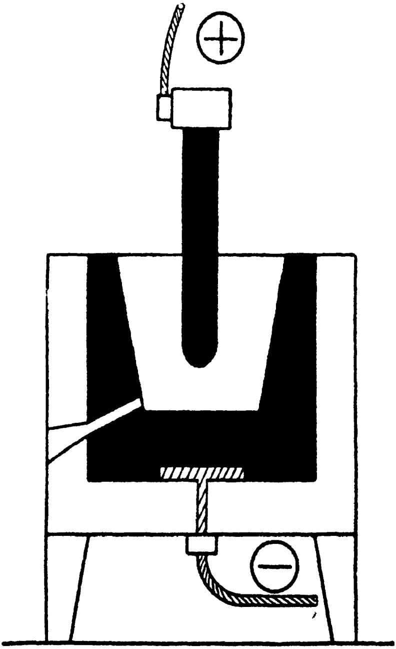

Fig. 3

HÈROULT TYPE FURNACE

The first to work the Hèroult process in France was the Société d'Electro-metallurgique Français, which now owns reduction works at Froges la Praz, Saussay, etc., capable of a yearly output of 8,500 tons.

The industry in this country has been fostered and developed largely by the technical skill and enterprise of an early pioneer, Mr. W. Murray Morrison, of the British Aluminium Company, Ltd. This company was founded in 1895 to mine bauxite and manufacture alumina in Ireland, to make the necessary electrodes at Greenock, to reduce the alumina at Foyers Falls, and to take over the old Cowles works at Milton, and refit them for the rolling and drawing of the metal. In 1905 the company commenced the famous water-power scheme at Loch Leven, and the extensive reduction works built at that time have since been more than doubled in capacity, while further water concessions are being utilised in Norway. The expansion thus indicated reflects something of what is taking place in other countries: considerations of space forbid enlargement on the numerous production works, alumina plants, rolling mills, welding companies and factories for the manufacture of aluminium ware and plant, which have sprung into robust life during the past decade. The world's annual output of aluminium is at the time of writing somewhere between 150,000–200,000 tons: the commercial success of this historically young metal has long been established on a sound basis, and in the wide versatility of its applications it bids fair to become one of the most useful discoveries of an age prolific in scientific enlightenment.

CHAPTER II

DISTRIBUTION

ALUMINIUM is a clean, white metal, with a faint bluish tinge something resembling silver. It is only slightly inferior to pure gold in malleability, and with a specific gravity of 2·65, is the lightest of all commercial metals, being one-third the weight of copper and half the weight of iron. In the rolled condition it is, weight for weight, equal in tensile strength to 40-ton steel. It may be cast, rolled, drawn, extruded, etc., with rather more facility than the majority of metals, and in its commercially pure state does not lend itself to corrosion. It will take a polish hardly inferior to silver, and its natural resistance to any form of tarnishing renders it in some respects superior to this metal, while the essential lightness of it for a given strength has resulted in the application of aluminium in countless forms to almost every industry.

Aluminium does not occur in the free state in nature but in its compounds it is the most lavishly distributed of all metals, being the normal base of all clays, loams, etc., and of a number of rocks and minerals, including such stones as the ruby, sapphire, garnet, and turquoise. Since the metal is thus apparently prevalent in every quarter of the globe, it is sometimes legitimately puzzling to a reader of the meagre popular literature available, that aluminium works do not exist, for example, on every brick-field. A brief examination of the factors affecting commercial production will make this clear.

In the first place, as previously stated, aluminium is entirely extracted at the present day by the electrolytic

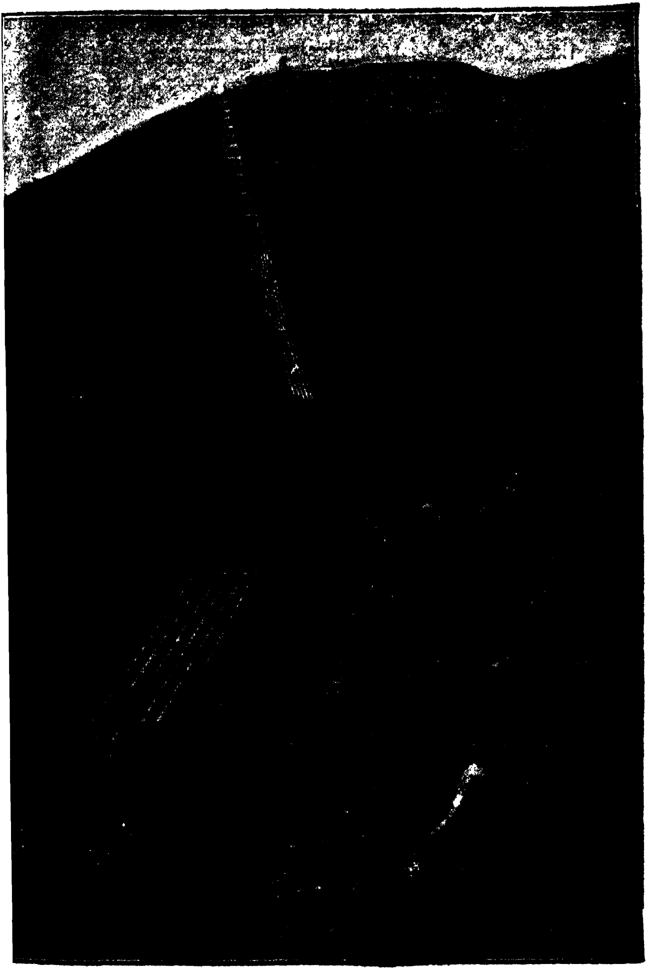

FIG. 4

HYDRO ELECTRIC DEVELOPMENTS IN SCOTLAND FOR THE PRODUCTION OF ALUMINIUM

80 per cent. cryolite and 20 per cent. impurities, but as delivered to commerce it takes the form of a fine white powder purified of the greater part of these impurities. Natural cryolite is not used to the same extent as formerly, synthetic processes for its production having been perfected. It may be prepared by treating calcium fluoride with sulphuric acid, forming hydrofluoric acid. This is neutralised with fluoride, which on being treated with an aluminium sulphate or fluosulphate, yields in turn an artificial cryolite.

The Hulin process largely used in France consists essentially in neutralising pure hydrated alumina with hydrofluoric acid. The resulting product is saturated with sodium dioxide, giving cryolite and pure oxygenated water—a useful bye-product. Artificial cryolite is rather more easily decomposed than the natural product, and a larger proportion is therefore used in practice.

Bauxite has now been located in various parts of the world too numerous to mention. The chief deposits of commerce are as follows—

British Isles.—Larne, Ireland.

France.—Departments of Ariège, Charente, Bouches du Rhone, Hèrault, Var.

Italy.—Abruzzi.

America.—Alabama, Georgia, Arkansas.

The French bauxites are not only the most extensive, but in addition they are richer in alumina than those from any other deposits worked on any scale. Analyses of specimens from any individual locality show a fairly consistent composition, but vary largely according to the locality of the bed, and may be roughly classified under three main headings—

(1) High in iron, low in silicon (red bauxite);
(2) Low in iron, silicon predominating (pale bauxite);
(3) Iron and silicon content about equal.

By permission of *Mr. W. Heinemann*

FIG. 5

MINING FOR BAUXITE IN THE OPEN

As an example of this, take the first three in the following table of typical analyses—

Locality.	Al_2O_3	Fe_2O_3	SiO_2	TiO_2	$CaCO_3$	H_2O
Red Bauxite from Var	65·20	21·90	0·29	3·40	—	14·10
White Bauxite from Herault . . .	77·90	0·10	2·19	4·00	—	15·70
Baux	72·61	8·2	10·0	—	—	9·0
Vochein, Germany	63·06	24·55	4·15	—	—	8·34
Georgia . . .	57·28	0·96	9·08	3·44	—	29·12
Alabama . . .	64·10	2·20	2·12	—	—	31·58
Arkansas . . .	63·05	2·65	2·00	—	—	32·20
Ireland	62·89	1·98	6·01	—	—	28·92

It will be noted that the French products take the lead on the score of alumina content, and that the impurities vary considerably according to the district of origin. Ores of lower grade than any of those tabulated were worked by the Central Powers during the war, and it is possible that improved methods of dealing with the ore may make the practice more general. Only a few years ago bauxites containing only 55–60 per cent. alumina were considered inferior from a commercial point of view, but nowadays when up to 95 per cent. of the alumina is recoverable in a well laid-out plant, this attitude may possibly undergo a modification. The analyses given above are commercial examples and omit the small percentages and traces of other impurities often present, a specimen analysed out giving generally something more like the following—

Alumina (Al_2O_3) . .	54·60
Ferric Oxide (Fe_2O_3) . .	19·04
Silicon Oxide (SiO_2) . .	6·81
Sodium Oxide (Na_2O) .	0·30
Magnesia (MgO). . .	0·22
Lime (CaO) . . .	0·02
Potassium Oxide (K_2O) .	0·03
Titanium Oxide (TiO_2) .	3·00
Sulphur Trioxide (SO_3) .	0·07
Phosphorous Pentoxide (P_2O_5)	0·01
Moisture (H_2O) . . .	0·90
Combined Water (H_2O) .	15·00
	100·00

Useful methods for determining the value of commercial bauxite are given in J. T. Pattison's book on aluminium, and also in the *Technical Chemists' Handbook* (Lunge). The various processes for the treatment of the ore prior to production proper are dealt with in detail in the following chapter.

CHAPTER III

PRODUCTION

PRESENT-DAY processes for the production of aluminium are directly dependant on the preparation of pure alumina. A great deal could be written on this, the most delicate and costly phase in the whole series of operations, but for the purposes of a book of this nature it would be well to confine ourselves to the essential points in the working of modern plants.

The object we have in view is to free the bauxite of the impurities Fe_2O_3, SiO_2, TiO_2, and H_2O, etc., and the initial stage in the treatment consists in crushing the ore to small nuts in a stone-breaker. If necessary, it is also washed, and any excess of sand present separated off by gravitation. The crushing assists thorough calcination, which in many cases is the next step in the operations, and which is carried out for the following reasons—

Firstly, most bauxites contain a certain amount of organic matter, and this tends to retard precipitation of aluminium hydrate at a later stage.

Secondly, there is generally an appreciable percentage of iron present, which may form soluble salts in the aluminate liquor. Iron is to be avoided as an impurity in aluminium, and it is advisable to exclude it at an early stage; in addition the presence of iron tends to cause trouble in the filtration of the crude sludge.

Thirdly, the amount of moisture present would often be sufficient to form a viscous paste and choke the screens in the final stages of crushing.

All these difficulties are met by calcination at a temperature not exceeding 400° C.: the organic bodies are destroyed and the moisture driven off, while the iron is converted into ferric oxide in which form it is more easily dealt with. The operation is not always necessary, some grades of bauxite being amenable to direct treatment after fine grinding, but where this initial calcination is considered desirable it generally takes place in a rotary kiln, lined with refractory material, and inclined from the horizontal. The charge is fed in at the upper end of the kiln, and as the latter revolves, the bauxite gradually works its way down to the discharge end, meeting on its way a column of hot gases provided by coal, producer, or natural gas, according to the most favourable local conditions. Discharging continuously at the lower end of the kiln, the calcined bauxite falls into a rotary cooler, where it meets with a column of cold air and gives up its heat. Or the cooler may be merely a horizontal steel drum revolving half-submerged in water; but the air-cooling system has the advantage that the air becomes heated in the process, and may be used in connection with the firing of the kiln.

The calcined bauxite now undergoes a further process of crushing, and since the finer the grind the greater the yield of alumina, it is usual to pass it through a 50–100 mesh screen—indeed some Continental producers prefer to finish off in a ball mill, and blow the pulverised product through a screen as fine as 5,000 mesh. From the grinding plant the bauxite is now conveyed to big storage silos, in readiness for the process proper, which consists in separating off the aluminium content in the form of soluble aluminates. There are numerous methods of carrying this out, but most of them have given place to the Bayer process, which at the present time is almost universally employed.

Bayer or "Wet" Process.—The finely ground bauxite is admitted to a vessel fitted with stirrers and containing a solution of caustic soda of a specific gravity of about 1·45. After intimate stirring the mixture is run into autoclaves or "digesters," long containers of mild steel provided with steam jackets and stirring apparatus. Here under a pressure of about 70 lb. per square inch, and increased temperature, the alumina is converted into soluble sodium aluminate, in accordance with the equation

$$Al_2O_3 + 6NaOH = 2Na_3AlO_3 + 3H_2O.$$

All caustic soda is recoverable, and presents no loss except that from mechanical waste and from the formation of silicates in cases where the bauxite holds an undue proportion of silica sand. The presence of lime corrects this latter tendency by transforming the silica into calcium silicates, and lime is therefore added when necessary during the earlier stages of crushing.

The liquor from the autoclaves is now blown out by its own internal pressure into large tanks also fitted with stirrers and heating elements, and is here diluted with washings from previous filtrations and such additional hot water as may be deemed necessary to assist filtration. The filtering takes place in three stages, the "red liquor" passing from the first filter press into a settling tank, and thence into another and finer filter. For about a week the clarified liquor is now allowed to remain in tall precipitation tanks, and during this period aluminium hydroxide is carefully stirred in to assist in the precipitation of the hydrated alumina, about two-thirds of which are deposited and afterwards separated off in filter presses in a white, amorphous form, the balance remaining in suspension.

We now come to the final calcination process, in which the hydrated alumina is raised to a temperature of 1,000° C., the water of hydration completely driven off, and the alumina transformed from an amorphous to a crystaline formation, in which form it is less liable to absorb moisture from the atmosphere during storage or transport by sea. The operation formerly took place in a reverberatory furnace, but where the scheme incorporates a well-laid-out plant to recover the finely divided alumina dust carried off by the flue gases, the rotary kiln is undoubtedly the better idea, because it dispenses with an undue proportion of labour. This is the stage at which the greatest loss of alumina occurs, a loss that was formerly in the neighbourhood of 50 per cent. Well conceived dust-recovery plants have done much to reduce this waste, but the fact remains that the average yield of alumina seldom exceeds one ton for every two tons of bauxite. When the water of hydration has been fully expelled, the alumina is discharged into a cooler and immediately packed in bags for transport.

The Bayer process may, therefore, be summed up as follows—

(*a*) The alumina content is dissolved out of the bauxite by caustic soda—leaving the impurities in suspension.

(*b*) These are separated from the solution by filtration.

(*c*) The filtrate, containing the alumina in an unstable solution, is treated with aluminium hydroxide, resulting in the precipitation of the alumina.

(*d*) This in turn is separated off by filtration.

The design of the plant varies in detail with the different producers: the firing of the kilns is arranged to suit the most economical local conditions, and there is some divergence as to the best means of recovering the fine alumina dust carried off in the final calcination process. But in its essentials the system outlined above is the one now used everywhere in the production of pure alumina, being more economical and smooth-working than any other process which has been tested for long on any commercial scale.

The main bye-product is the residue from the first filtering, after the caustic soda treatment. This is known as "red mud," and it may be washed free from alkali, dried, and briquetted, in which form it may be smelted to recover the iron content like any normal iron ore. To the present date, however, there is no very ready market for this bye-product; it is used to a limited extent in the purification of coal gas, but the process employed demands a degree of porosity in the constitution of the "red mud," which is not normally found in the product of the Bayer system.

The liquor from the final filtering is of course re-concentrated to its original density in evaporators, and is used over again.

The Bayer process has received prior consideration because it comes first in point of importance, but the subject may not be equitably dismissed without reference to one or two other methods of past and possibly of future interest.

In the early days what is known variously as the "carbonate," "dry soda," or "Deville-Pechiney" process held the field, and indeed still has claims where bauxite is high in iron. Where there is much silica present, the method is never used, because silica is attacked by soda at the temperatures employed.

The calcined, powdered bauxite is thoroughly mixed with about 1½ times its weight of calcined carbonate of soda and a percentage of pulverised coal. The mixture is then "sintered" in a rotary furnace for about four hours at a temperature of 1100°–1400° C. This operation requires some care, the temperature being maintained at a point sufficient to form the ingredients into an homogeneous mass without melting them. At this temperature the sodium carbonate is split up into carbonic acid gas and soda, the latter combining with the alumina in the bauxite to form sodium aluminate. When the evolution of carbonic acid gas has ceased, the mass is quickly dissolved in boiling water. The sodium aluminate goes into solution, while the insoluble oxides of iron, titanium, and the greater part of the silica, are precipitated. The dissolving process takes place in a vessel fitted with stirrers and some dispatch is necessary to avoid premature precipitation of aluminium hydroxide Caustic soda may be added to strengthen the soda alumina ratio, and the temperature must not fall below 80° C.

The insoluble residue, mainly ferric oxide, is separated off in a filter press, collected and used in gas purification, while the washings from the filters are used over again to assist in the dissolution of a fresh charge from the furnace.

The filtered liquor passes into tall cylindrical vessels, where it meets with carbon dioxide or flue gases: the aluminate is decomposed into practically pure aluminium hydroxide of dense granulated formation—

$$2\,Na_3Al\,O_3 + 3\,CO_2 + 3\,H_2O = 2\,Al\,(OH)_3 + 3\,Na_2\,CO_3,$$

and is pressed, washed and calcined.

Peniakoff Process.—The main divergence in this method from that previously described lies in the salt employed—sodium sulphate taking the place of carbonate, and the aluminium being recovered as sodium aluminate according to the formula—

$$2Al_2O_3 + 6\,Na_2SO_4 + 3\,C = 4\,Na_3Al\,O_2 + 3\,CO_2 + 6\,SO_2$$

The furnace reaction takes place at 1,400° C., air being admitted to avoid formation of sulphides, and the sintered mass is then put through much the same treatment as it receives in the dry soda process. Sulphur dioxide is given off during the sintering, and this is recovered and converted into sulphate and hydrochloric acid, the former being used over again while the latter is a useful bye-product. In both the dry-soda and Peniakoff processes there is an appreciable bye-product of soda, which is crystallised off and marketed.

It will be noted that all the methods so far referred to have in common the feature that they obtain the aluminium in the form of a soluble aluminate. There are, however, several methods patented which break new ground, and although, as far as the author is aware, none of these have reached a stage at which a useful commercial comparison might be made, two of them are considered of sufficient general interest to warrant a brief description.

GRIESHEIM-ELEKTRON PROCESS.—The patents provide for the isolation of the aluminium content in bauxite in the form of sulphate. After the usual preparation of calcining and pulverising, the bauxite is boiled with sulphuric acid, such excess of acid being used that the iron remains in solution when the aluminium sulphate crystalises out.

SERPEK PROCESS.—This is an interesting process which is being developed in France under the auspices of the Société des Nitrures, and which is attracting wide attention owing largely to the versatility of its potential by-products.

Great interest is being taken at the present day in the fixation of atmospheric nitrogen by oxidation in the electric furnace. Serpek conceived the idea of fixing the nitrogen as aluminium nitride by the decomposition of bauxite by carbon in the presence of nitrogen. This results in a product which contains 24 per cent. of

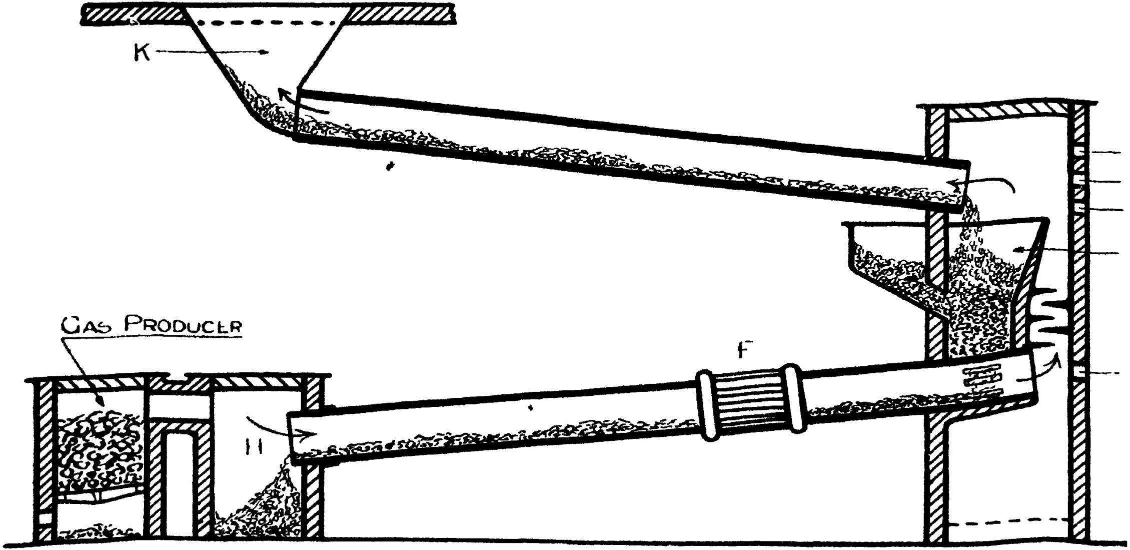

Fig. 6
DIAGRAM OF SERPEK APPARATUS

nitrogen, and which may be subjected to the action of soda solutions to form ammonia and aluminate of soda, the latter being dealt with as in previously described processes, yielding alumina.

In practice, Serpek uses an apparatus much as shown diagramatically in Fig. 6. There are two kilns superimposed. Bauxite is fed in at K, through the passage by which the waste gases make their exit to the flues, by which it is thus preheated. Passing down the upper kiln, it becomes calcined and falls into the hopper at M. It is here mixed with carbon and passed on into the lower kiln, where it runs the gauntlet of an electric resistance furnace F, which raises its temperature to 1,800–1,900° C. In the presence of a column of nitrogen and carbonic oxide, supplied by a gas producer and passing through the kilns in the opposite direction, this temperature is sufficient to convert the bauxite rapidly into aluminium nitride. The carbonic oxide passing from the lower kiln is mixed with air at the ports CCC, and is burnt, the heat evolved being responsible for the calcination process in the upper kiln, while the nitrogen combined with the bauxite falls into the receptacle H as nitride of alumina, which is dealt with as described above.

The process is not only an ingeniously worked out method of fixing atmospheric nitrogen, opening up a potential source of ammonia, fertilisers and nitric acid, but the main bye-product which is practically pure alumina should find a ready market in the production of aluminium. The process appears to hold some promise, and its development will be watched with interest.

CHAPTER IV

PRODUCTION (CONTINUED)

FURNACES.—All furnaces designed for the electrolytic process are essentially the same, however much they may, and do, vary in constructional detail according to local ideals and requirements. For convenience of working they are generally installed in single or double rows down the length of a lofty, well-ventilated building, and a passing glance would generally leave the impression of a neat perspective of low rectangular tanks or boxes of mild steel, supported on brickwork. Within these oblong receptacles is first a lining of refractory material of low thermal and electrical conductivity, and within this a heavier lining of carbon pisé forming the cathode. The pisé is made up of a grist of gas or petroleum carbon with a suitable oil or tar binding, and is rammed into place much on the lines shown in Fig. 7, with plates of iron embedded therein to form the cathode connection. The carbon lining is often rammed straight into the iron container, and simply rests on a layer of refractory brickwork. The vessel thus formed may be given a preliminary baking in another building, a coal or coke fire being maintained in it for a few days. But even when this is done the starting up of a new furnace of this pattern is always accompanied by the emission of clouds of tarry smoke, and to minimise this nuisance, and at the same time to afford a better furnace conductivity, it is becoming more general practice to embed electrodes of high purity in the pisé as shown in Fig. 8. The cathode connection is made direct to these electrodes, which are usually of slightly larger aggregate area than the anodes. This idea is carried still further by some producers, who make the cathode in the form of a large crucible of carbon of the same consistency as the anodes, formed and baked as a distinct unit. There is the advantage in this system that a worn-out furnace may be replaced with a minimum of trouble, but the writer has no figures to show whether this advantage coupled with efficient conductivity and freedom from smoke, is not counterbalanced by the extra expense and potential liability to fracture during operation. Furnaces gradually deteriorate owing to absorption of the elements of the " bath " and the superficial formation of carbides which affect the conductivity.

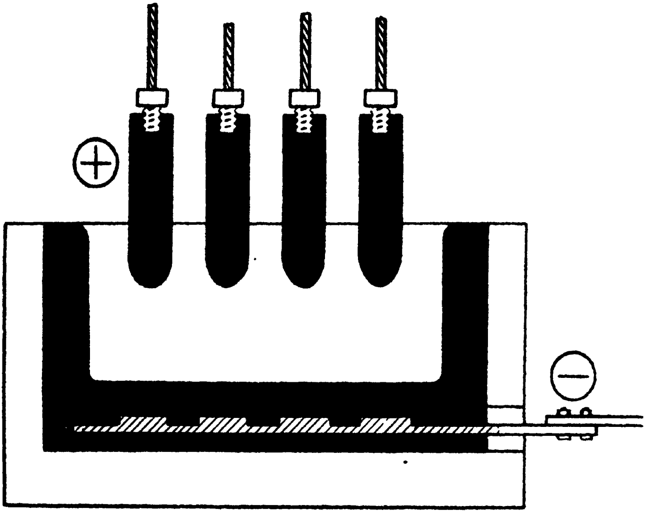

FIG. 7

DIAGRAM OF HALL-HÈROULT FURNACE

Where large units are concerned it is probably the better all-round practice to re-build them *in situ,* with the provision of extra furnaces which may be gradually "broken in" during the few days previous to the switching out of a unit which is falling in efficiency. But a number of furnace houses are provided with either travelling cranes or with rails, by which the furnace may be bodily removed to another building and dealt with at leisure, and a new one substituted in its place.

Into the interior of the furnace are suspended the groups of anodes, and these vary in size and section and general appearance even more than the furnaces. They may be round in section, or square or oblong, and they may vary in size from 3 in. to 10 in. in diameter, and in length from 3 ft. down to mere blocks, according to the lines along which individual producers have developed. The main considerations are simply that they should carry a current of from 25–50 amps per sq. in. into the furnace without undue drop in voltage or heating up, that the waste of anode in the way of stumps be reduced to a minimum, and that the space factor be as small as is consistent with efficient operation.

Thus, the anode connections for example formerly took the form of heavy clamps of copper or bronze, sometimes water-cooled. They were unwieldy, absorbed heat radiated from the furnace, occupied a great deal of space and gave a high waste factor in the anode because large stumps had to be discarded. Nowadays the connection is made either an integral part of the anode by being embedded therein during its manufacture, or a threaded hole is formed in either or both ends of the anode and the connection screwed in or cast in with molten bronze. This axial arrangement has two major advantages: the connection is shielded from direct radiation from the furnace, and the stump of a nearly used-up anode may be almost entirely immersed in the bath, reducing a costly form of waste. In some cases, indeed, the stump is screwed to the nether end of a new anode and entirely used up. Where this is done, and where connections are screwed into the carbon, a liberal lagging of graphite paste is applied to the threads to form an intimate contact. Anodes contract ·5 per cent. on cooling after the final baking stage in their manufacture, and allowance must be made for this when designing the screw threads.

The anodes are suspended in the bath in clusters of from 8–12, closely grouped and clamped to a heavy frame support. The cluster as a whole, or each individual anode, may be raised or lowered by mechanical means, in order to control the current to the furnace, and to distribute it equitably amongst the electrodes. The consumption of anodes may be reduced to 1 lb. for every pound of aluminium produced, but in practice it is more often in the neighbourhood of 6–8 lb., because of the rejection of unused ends. These may be crushed and gristed to go to the manufacture of new electrodes, but with the price of the latter at about £15 a ton, careful economy in the furnace house is a consideration of first importance, and is well-paid by results.

Notes of the Manufacture of Electrodes.—The first necessity in an anode is purity. This is essential in the production of uncontaminated metal, and would appear to indicate the use of pure graphite. The cost of this material, however, precludes its employment, and anodes are now generally made of petroleum coke, a comparatively pure form of carbon obtained from the distillation of shale oil, and yielding only ½ to 2½ per cent. ash. In the manufacture of electrodes it is a general rule that the higher the specific gravity the better the conductivity, and the less the liability to crack through internal bursting strains during working. Any volatile matter which may increase the porosity of the finished anode is therefore removed from the coke by calcination as a preliminary measure.

The next step is crushing and gristing, an important stage which calls for a fair level of personal experience.

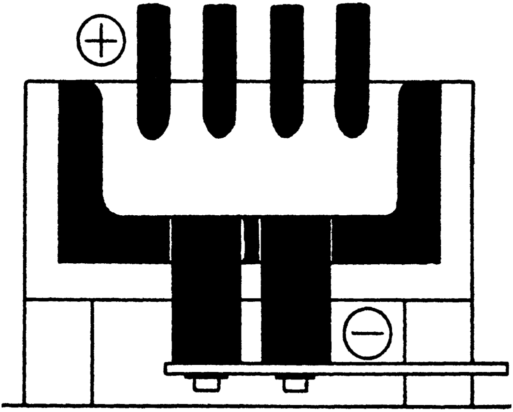

FIG. 8

MODIFIED HALL-HÈROULT FURNACE

J. T. Pattison, in his book, *The Manufacture of Aluminium,* gives the following as a good gristing—

To pass through	100	meshes per sq. in.	40	parts
,, ,, ,,	60	,, ,, ,,	15	,,
,, ,, ,,	30	,, ,, ,,	20	,,
,, ,, ,,	16	,, ,, ,,	15	,,
,, ,, ,,	16–18	,, ,, ,,	10	,,

The grist is conveyed to a mixing machine and thoroughly mixed into a paste with hot tar at about 90° C. This paste is then moulded in a hydraulic press under a pressure of one ton to the sq. in., and the moulded anodes are removed to a furnace where they are baked for from 5–8 days at a temperature of 1,000° C.

The foregoing remarks indicate the chief points in the process: in practice there is naturally some divergence in detail. If the manufacture of electrodes has not yet entered the realm of exact science, the fact remains that the consistent production of good, high density carbons which may be relied upon not to crack or "waist" during operation, seems still to be a function involving a fairly high personal factor, and is best left to those firms who have specialised in this work for some years and have the experience.

Breaking in a New Furnace.—To start operations, the bottom is covered loosely with granulated carbon, and the electrodes are lowered thereon. As the temperature rises, cryolite is added in small quantities, and the anodes are raised in accordance with the increase in volume of the bath until the latter is sufficient to carry the full current. This "breaking in" operation takes several days of careful watching and manipulation. When the full current is running alumina may be stirred in little by little and the electrolytic action proper commences.

The reaction at its simplest may be written—

$$Al_2\ O_3 = 2Al + 3\ O$$

The aluminium accumulates on the cathode bottom, while the oxygen liberated in contact with the anodes combines with the carbon therein to form carbon monoxide, which is at once burnt, forming carbon dioxide in contact with the air. The complete reaction, therefore is more truly written thus—

$$2\ Al_2O_3 + 3C = 4\ Al + 3CO_2$$

Now, in theory, at the applied tension of 5–8 volts, the cryolite remains unaffected. In practice, however, the electrolytic action is not entirely confined to the alumina: the solvent is to a certain extent split up, resulting in the formation of fluorine gas at the anode and the deposit of sodium at the cathode. Not only is sodium detrimental to the purity of the aluminium, but this secondary electrolysis causes an unnecessary waste of cryolite. The remedy is the addition of alumina, but this must be kept within bounds for the following reasons. The melting point of cryolite is about 1,000° C.; an addition of 5 per cent. alumina lowers this to 915° C., while a further addition of 8 per cent. to 20 per cent. again raises the melting point to 1,015° C. The most efficient temperature to operate the furnace is from 800° C. to 950° C., and the alumina must therefore be limited to 5–6 per cent. In practice this percentage provides too fine a margin of working, between the deposit of pure aluminium and the point at which decomposition of the cryolite commences, and the remedy is found in some form of flux which will reduce the melting point and give a wider range in the use of alumina. The fluxes used vary with each producer, but all have in common the object of enabling a greater body of alumina to be taken into solution without the necessity of raising the temperature beyond the limits of industrial efficiency. Hall used a mixture of 33 per cent. cryolite, 20 per cent. calcium fluoride (fluorspar), and 44 per cent. aluminium fluoride, which not only gives a melting point of 800° C., but dissolves 10 per cent. more alumina than pure cryolite. The further addition of sodium chloride lowers the melting point to 700° C., and is sometimes done to get a reluctant furnace under way: the sodium chloride rapidly volatilises, and is used mainly as a temporary measure.

The addition of fluxes also enables some minor modification to be effected in the relative densities of the components of the " bath."

According to Professor J. W. Richards, the specific gravity of the materials present are as follows—

	Solid.	*Fused.*
Commercial Aluminium	2·66	2·54
Commercial Greenland Cryolite . . .	2·92	2·08
Commercial Greenland Cryolite saturated with Alumina	2·90	2·35

It will be seen from this that when in a solid condition the metal is lighter than the other materials in the bath, but that it is heavier than these in the fused state. It is lighter by ·24 in the solid and heavier by ·19 when molten. It is, therefore, just possible for the aluminium to sink to the bottom of the furnace. If it did not—if it floated on the surface or remained in suspension, it would partially short circuit the current and disorganise generally the whole process of electrolysis. It will be readily appreciated by the reader how narrow are the limits of working imposed by this factor.

The addition to the bath of, for instance, fluoride of aluminium, in the proportion of 2 molecules of the fluoride to 1 molecule of cryolite makes for a wider margin of working, the mixture then giving the following densities—

Solid, 2·98 ; fused, 2·14 ;

this figure giving a balance of ·040 in favour of molten aluminium in place of 0·19 as quoted above. Nevertheless, the prime utility in the use of fluxes lies in their quality of reducing the melting point, with consequent ability of increasing the percentage of alumina, giving in effect more mental elbow room in the operating of the furnaces.

These points give an indication of the care and experience necessary to successful production, the judgment required in the choice of a suitable flux and the efficient supervision in the furnace house; and they also throw some light, perhaps, on the question as to why the manufacture of this metal has always been associated with a measure of secrecy.

To assist furnace hands in their duties pilot lamps are generally connected across the main terminals, which light up when the bath reaches a certain resistance, and give ample warning of the need of alumina. Unnecessary loss of heat by radiation is prevented by covering the surface of the bath with a layer of alumina, which melts at the hottest point, near the electrodes. When additional alumina is required this crust is broken in, and the electrolyte stirred occasionally to assist dissolution, and fresh alumina is laid on the surface. If the furnace becomes too hot the flames around the anodes increase in volume and turn yellow: the anodes, which are kept at an average distance of 2–3 in. from the cathode, are then lowered a little. Every two or three days, according to the capacity of the furnace, the molten aluminium is tapped off, either *via* a hole in one of the sides, or by ladling, a sufficient amount of metal being left to continue the operation. Before being delivered to commerce, the metal is invariably re-melted in a reverberatory furnace and cast into ingots, slabs, notched bars, etc.

The average yield of metal is 1 lb. for every 2 lb. of alumina, and the consumption of anodes may with care be brought down to 1 lb. per pound of metal produced. Theoretically no consumption of cryolite occurs, but as has already been seen, there are losses in the cryolite and fluxes, which amount to about ¼ lb. per lb. of aluminium, and these must be made good from time to time. The efficiency of a normally working furnace is high—90–95 per cent. of that theoretically possible, but taking into account change of furnaces, operating mishaps, etc., over the period of a year, the industrial efficiency varies from 50–85 per cent. At the working voltage of 5–8 volts, the current through the bath varies from 15,000–20,000 amperes in large units, while the smaller capacity furnaces take from 8,000–10,000 amperes. The metal produced by the process may have a purity of 99·9 per cent., but for commercial purposes a standard of 99·20–99·60 per cent. is maintained, the variation being according to customers' requirements. The impurities are chiefly iron and silicon, certain small percentages of these being apparently almost inseparable from the production of aluminium. Iron occurs as a compound, $FeAl_3$, which is for all practical purposes insoluble in solid aluminium, and is visible in polished metal as a hard, white compound which will take a high polish. Silicon, which is present in percentages seldom below 0·1 per cent., may be detected from the iron by its slightly darker appearance. Both these impurities are practically impossible to remove from aluminium, and the only remedy is to prevent as far as possible their inclusion during production. Hence the need for constant supervision throughout the processes, and for absolute purity in the materials used. This particularly applies to the anodes, which are immersed in the fluid bath and which must therefore be of high purity and give a minimum of ash.

The electrolytic process is one of those fatally simple ideas which look so attractive on paper, beautifully conceived and straightforward enough to describe. In practice, owing to the essential delicacy of the series of operations and the difficulty of ensuring a consistent level of purity in large consignments of materials, the production of pure metal from one year's end to another demands experience and able management. The progress of the metal, from the preparation of pure alumina to the final casting into slab form for rolling, is girt about with pitfalls, and the early history of aluminium is chequered with the failure of concerns which had not just that mead of experience essential to the success of this most intriguing of industrial processes.

As delivered to commerce the metal has a tensile strength of 5–8 tons per sq. in. in the cast state with 2–3 per cent. elongation, while rolling or drawing bring these figures up to a maximum of 14–15 tons per sq. in., with 2–4 per cent. elongation, depending on the amount of work done on the metal.

FIG. 9

TRAIN-LOAD OF ALUMINIUM INGOTS FOR SHIPMENT, KINLOCHLEVEN

The effect caused by the introduction of the electrolytic process may be traced in a comparison between the figures for production and selling price of the present day with those of some thirty years ago. In 1887 aluminium cost about £2,250 per ton. By 1890 this had fallen to £1,085 per ton, and the world's annual output had reached the figure of 40 tons. In 1892 the price was still high at about £750 per ton, but by this time the electrolytic process was beginning to make itself felt, and the world's output was rapidly rising. By 1894 this had reached the 1,000 tons per annum line, and the next three years saw this figure more than doubled, while the price had fallen in sympathy to £145 per ton. In 1914 the output had reached a figure exceeding 20,000 tons per annum at an ingot price averaging £80–85 per ton, and while the war brought an artificial inflation of prices in this as in every commodity, it also brought great advances in production facilities, resulting to-day in a world's annual output of something between 150,000 –200,000 tons

CHAPTER V

ALLOYS OF ALUMINIUM AND THEIR TREATMENT

THE subject of the alloys of aluminium opens up a wide field, and it will be best to take only those which enter largely into industry. Aluminium goes readily into solution with percentages of most of the common metals, with the notable exceptions of lead and antimony, forming alloys which may firstly be divided into two classes—

(*a*) Heavy (containing under 20 per cent. Al.);
(*b*) Light (containing over 50 per cent. Al.).

In the first class the most important industrially is aluminium bronze, consisting of 90 per cent. copper and 10 per cent. aluminium. It is mixed by heating copper to rather above its melting point and then plunging a stick of aluminium beneath the surface, causing first a chilling of the melt, and after a short interval a more or less violent reaction accompanied by rise in temperature, indicating a definite chemical combination. Only pure electrolytic copper must be used, and the percentage of the light metal must be added with care, for while 5, 7½ and 10 per cent. additions go into solution, 6, 7, and 8 per cent. form only mixtures with very different physical properties.

Properly alloyed, the resulting product is a bronze having a colour resembling gold, and a tensile strength of 35–40 tons per sq. in. It has a greater shrinkage than ordinary gun metal, and is rather more difficult to machine. It is used in decorative work in the form of an imitation gold leaf, for the cheaper jewelry, for an anti-friction metal, and for marine propellors, and such situations as require a tough material not easily corroded. With the addition of manganese, a bronze of this nature is much in demand where castings have to stand repeated shocks, as in quick-firing guns and parts of automobiles.

(*b*) *Light Alloys.*—Alloys of this class are legion, and may be usefully considered under two heads—

(*a*) Alloys for casting ;

(*b*) Alloys for constructional work in the rolled or drawn forms.

Now the discussion of light casting alloys is, as will be shown later, almost inseparable from the casting operation itself: at any rate they are more interdependent than is very generally supposed. Any points, therefore, wherein the casting of aluminium diverges from common foundry practice may acquire more significance for the average reader if dealt with in this chapter.

Pure aluminium is seldom used for castings subjected to stress owing to its comparative softness, porosity when cast, and general lack of strength. In the cast state it has a tensile strength not much exceeding 6 tons per sq. in., with a high elongation, and it is therefore usual to add a hardening agent. Generally, any increase of tensile strength and hardness is at the expense of ductility in the cast state, and where castings are to be subjected to impact it is inadvisable to increase the hardening beyond a certain point. Again, the hardening effect of the metals commonly used in alloying increases rapidly at first, but the addition of metal beyond a certain point decreases in its effect on the tensile strength, and as the specific gravity is steadily rising the alloying is best controlled within fairly narrow limits from the point of view of strength for weight.

There are two main hardeners, dividing casting alloys broadly into two classes, those in which zinc is the hardening medium and those in which copper is used.

Zinc is the cheapest known hardener of aluminium, and may be added up to 30 per cent., there being an improvement in mechanical properties up to 15 per cent.

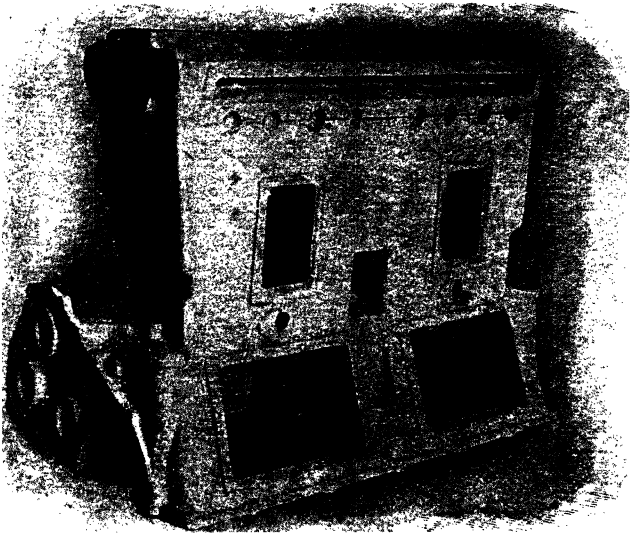

FIG. 10

A FOUR-CYLINDER ALUMINIUM BLOCK CASTING, CAST IN ONE WITH TOP HALF CRANK CASE

Alloys with this medium are cheap, melt at a low temperature, are very easy to cast, and are not too brittle in anything below 20 per cent. zinc. They do not machine well, and the machining properties are much improved by 2–3 per cent. copper. They are not recommended for cylinder castings owing to their porous propensities, and they have the reputation of being liable to give under fatigue stresses. This latter may be due to impurities, but is endorsed by one or two experiences of the writer's during the war.

For high-class work, for castings required to withstand the pressures and fatigue stresses that are met with in modern high-duty aero and automobile engines, the preference is turning surely to alloys with copper as the main hardening factor. Aluminium copper alloys have a higher strength-weight ratio, stand up well to repeat impact tests, and are less porous to hydraulic pressure. Owing to the higher melting-point of copper, greater care is necessary in the mixing to avoid "burning" the aluminium, and this higher melting temperature and lower fluidity in the alloy make casting more difficult than with the zinc group.

The addition of copper up to 10 per cent. improves the mechanical properties considerably, although once the 8 per cent. line is passed the gain is not proportional to the increase in weight. The addition of 1–2 per cent. pure manganese with the copper, in the form of a manganese-copper alloy, gives the alloy a greater resisting power to the influences of air and water, and the peculiar property of increasing in tensile strength with rise of temperature up to 250° C. Tensile strengths of from 9–12 tons per sq. in., with an elongation of 7–8 per cent., have been obtained with these copper-manganese alloys, which give good, dense castings, and are easy to machine. Alloys of this class are used to a wide extent in aluminium pistons, and in some cases for cylinder blocks, but in the latter application the author found ordinary copper alloys with or without an addition of tin to give better service. For ordinary purposes the most commonly employed proportion is round about 6 per cent. copper, and when cast in sand an ultimate strength of 9–10 tons per sq. in. should be obtained, with an elongation of 5–8 per cent. For special circumstances requiring a higher degree of stiffness or hardness, 12 per cent. copper may be added, but it should be borne in mind that beyond 15 per cent. the alloy becomes brittle and the tensile strength begins to fall off.

Nickel has much the same effect on aluminium as copper, and where very good machining properties are desired a nickel alloy often meets the case better than any other. An alloy containing 25 per cent. nickel, however, disintegrates very rapidly owing to internal electrolysis, so that nickel is used sparingly, a useful alloy consisting of 5 per cent. nickel and 2–3 per cent. copper. Aluminium alloys readily with tin, a small percentage of either metal largely affecting the characteristics of the other. The general effect of tin is to make the alloy more brittle; it is said to make casting easier since it is claimed to reduce shrinkage, but the writer's experience with tin, such as it is, hardly seemed to bear this out. In the case of a large batch of pistons in which the steel bushes to carry the gudgeon pins were " cast in," cracks developed in the bosses carrying these bushes, and this trouble was eliminated when the tin element was omitted. This is anything but conclusive, but it is evidence and as such is not without interest. A table of analyses of alloys in general use during the war, and which came under the observation of the writer, is appended herewith.

Out of a great number of alloys observed, none seemed to stand up to war conditions so consistently as 92 per cent. aluminium, 7 per cent. copper, and 1 per cent. tin. There is a very useful amount of information available now with regard to the Brinell, elasticity, impact, tensile strength, etc., of standard alloys. These tests are well understood and are standard routine in any up-to-date automobile or aero engine works. But in the matter of the quality in an alloy to stand up to prolonged fatigue stresses we are not so well posted, or perhaps it is that the information is not so readily obtainable. In any case the last-mentioned alloy was one of the few in the writer's experience to withstand long and severe vibrational stresses with consistency, and whether this was due to its analysis or to some obscure factor such as the temperature of pouring (the castings all came from one firm) is not definitely known.

And this introduces us to a factor which is intimately concerned with the success or non-success of aluminium casting alloys, and incidentally to aluminium foundry practice.

Given a certain standard light alloy known to be suitable for a given work, there are three phases in the production of the casting in which some knowledge of the peculiar properties of these light alloys is essential to success. These are, drawing the design, making of the mould, and pouring the metal.

Taking these in order, aluminium alloys shrink some $\frac{3}{64}$ in. per ft. on cooling, and margin must be allowed for this in the patterns and core-box. Thin sections and complicated coring made surprising strides during the war, but as a general rule should be avoided as far as possible. The metal has a notoriously low tensile strength at temperatures just below solidification, and it is at this point that a great part of the shrinkage takes place: the casting should therefore be designed in such a way that thickness variations and sharp changes in direction are as far as practicable eliminated. Ample fillets should be provided at sharp angles, the sharper the angles the greater the radius of fillet. The failure to produce sound castings utilising the peculiar advantages of aluminium can more often be traced to the designer than to lack of experience or care in the foundryman.

With regard to moulding, owing to the low density of the metal, the gases generated during pouring tend to make their escape through the molten metal itself, rather than through the sand, resulting in spongy castings. The remedy is to encourage porosity in the mould, and the best way of obtaining this is by the use of green-sand, lightly and evenly rammed. It must be remembered that the metal is about a third of the weight of other casting metals, the mould need not be rammed so closely as with iron or brass, and the lighter ramming will provide the required porosity without giving rise

FIG. 11

A SPECIMEN OF DIFFICULT CORING

to trouble such as "swells," etc. The finished mould may be dusted over with French chalk or lycopodium—graphite should not be used if a clean casting is desired.

Cores must offer little resistance to the shrinkage of the metal, and must therefore be constructed to crush easily. Provided this principle is kept in view, any one of the numerous sands and binders may be used. A resin binder is peculiarly useful because it softens immediately on heating and the core crushes readily: the latter should be withdrawn while the casting is hot, or it will harden to an extent that will make removal difficult.

Large cores within thin walls are frequently a cause of trouble: a large core which is strong enough to be handled generally has a compressive strength too high to be overcome by the metal before a crack has formed—a point for the designer.

A third of the causes of failure in casting any non-ferrous metal is due to illogical gating. Bad gating may, and often does, produce passable castings in other metals—in aluminium it does not. The metal has to be poured rapidly, and preferably in one unbroken stream. If this is done, the film of oxide which forms instantly on the surface of the falling metal acts in the nature of a tube preventing further formation of oxide and its inclusion in any serious degree in the casting. This postulates large gates, larger even than those used in the case of gun-metal or brass. Generally also, gates are better at one end rather than at the middle, and invariably better results are obtained by gating from the bottom upwards. In addition, risers of good height and heavy section should be used.

The difficulty about the provision of sufficiently tall risers in aluminium casting is a very real one. Risers improve the homogeneity of the casting to a marked degree, but since the density of the metal is about a third of that of other common metals, to give an equivalent effect risers should logically be three times as high, an impracticable scheme.

One London firm has circumvented this factor in an ingenious manner by the application of centrifugal force during the pouring operation. The moulds are clamped around the periphery of a revolving turntable, and are provided with a common gate at the centre. The table is rapidly revolved by an electric motor and the melt poured, the metal flowing under centrifugal force into the most intricate corners of the moulds, and giving castings of good homogeneity, free from blowholes. Not very inferior results, however, may be obtained in any foundry, provided that care is taken in the scheming of the gates, the metal is poured rapidly, and at the correct temperature.

As an indication of the effect of pouring temperature on the physical properties of the casting, the reader is referred to Table 1, shown herewith. The control of the temperature within fine limits has become an essential factor in aluminium foundry work, and it is for this reason as much as for the economy of working that high-pressure gas, or oil-fired, furnaces are coming into general favour. The melting in these furnaces is clean and safe, a flux is unnecessary, the metal is not easily " burnt," and the cost of melting is more than halved.

Aluminium has a high affinity for oxygen, and at temperatures much above the melting point oxidation occurs rapidly. The oxide has much the same specific gravity as the metal, and is liable to be occluded throughout the melt, rendering removal very difficult and satisfactory casting impossible.

When copper is fed in it should be in the form of an

TABLE I
A List of Aluminium Alloys Showing Influence of Pouring Temperature

(Abstract reprinted from *The Metal Industry*, May, 1913.)

Composition.					Poured at Low Temperature.		Poured at High Temperature.	
Al	CU	Zn	Sn	Mn	Degs. F.	Tensile Strength in lbs. per sq. in.	Deg. F.	Tensile Strength in lb. per sq. in.
100					1,400	10,500	1,600	8,000
98	2				1,225	13,800	1,600	11,500
96	4				1,225	15,500	1,600	13,000
94	6				1,225	17,600	1,600	14,500
92	8				1,225	20,000	1,600	15,500
90	10				1,225	21,000	1,600	16,000
88	12				1,225	22,500	1,600	17,500
96		4			1,225	13,000	1,550	10,000
92		8			1,225	17,000	1,550	12,700
88		12			1,225	21,000	1,550	14,000
84		16			1,225	24,000	1,550	17,000
80		20			1,225	27,000	1,550	20,000
76		24			1,225	30,000	1,550	24,500
72		28			1,225	33,000	1,550	27,500
68		32			1,225	35,000	1,550	30,000
64		36			1,225	37,000	1,550	33,000
94	3	3			1,225	17,000	1,550	13,000
91½	7½	1			1,225	18,000	1,550	14,000
91¾	8	¼			1,245	20,000	1,550	17,000
91½	8	½			1,225	20,500	1,550	17,000
91	3	6			1,225	19,000	1,550	13,500
90	7	3			1,225	19,500	1,550	15,500
89	6	5			1,225	20,000	1,550	15,000
88	2	10			1,225	23,000	1,550	15,500
88	4	8			1,225	23,500	1,550	17,000
85	5	10			1,225	24,000	1,550	18,500
84	7	9			1,225	25,000	1,550	18,000
85	3	12			1,225	26,000	1,550	18,500
82	3	15			1,225	28,500	1,550	19,500
81½	3	15		½	1,225	30,000	1,550	20,000
78½	2½	19			1,225	33,000	1,550	25,000
81	4	15			1,225	32,000	1,550	23,000
76	2	22			1,225	36,000	1,550	28,000
73	2	25			1,225	37,000	1,550	33,000
69¼	1¾	30			1,225	42,000	1,550	34,000
72	3	25			1,225	37,500	1,550	29,500
98				2	1,200	19,000	1,550	18,500
91¾	8			¼	1,290	20,000	1,550	17,500
92⅝	7			⅜	1,200	19,000	1,550	16,000
93½	6			½	1,250	18,500	1,550	16,500
95	4			1	1,250	16,000	1,550	15,000
90	8		2		1,215	18,000	1,475	15,700
92	5		3		1,215	16,800	1,500	15,000
95				5	1,250	20,500	1,400	20,000

alloy, formerly 50 per cent. copper and the remainder pure aluminium, but now more generally 25 per cent. copper. The latter alloy gives a still lower melting point, obviating any danger of burning the melt during

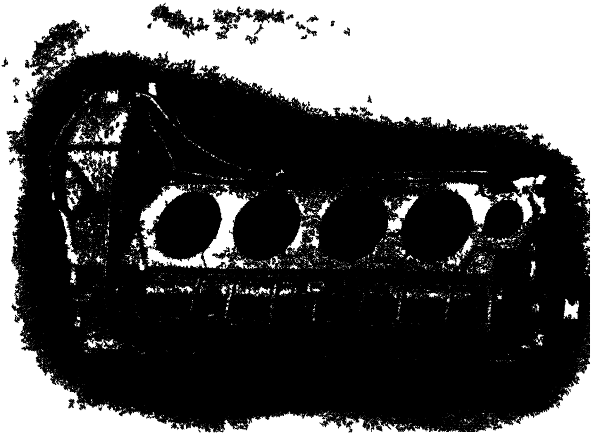

FIG 12

CASTING OF TOP HALF CRANK CASE OF EIGHT-CYLINDER 250 H P. AIRCRAFT ENGINE

the addition of the copper, but allowance must be mad for the new aluminium in the quantity of the melt.

The temperature of pouring should always be as nea the melting point as possible. An increase of 2 tons pe sq. in. in tensile strength may be obtained by adherin to this rule, accompanied generally by an advanc in both yield point and elongation, and always by th production of sounder castings.

A safe rule for average alloys is 650° C. (1,200° F.), and an up-to-date foundry will depend on the use of a pyrometer rather than on any rule-of-thumb method, which involves too high a personal factor for consistent output. Over-heating, *per se*, is not so directly detrimental as formerly supposed, although in an open-type crucible it is to be avoided: the main point is that the metal must be allowed to cool down to its correct temperature before pouring.

Chill and Die Casting.—No chapter concerned with the casting alloys of aluminium would be complete without a few notes on their characteristics as applied to chill and die-casting. This form of casting has made striking progress during the past few years, particularly in the States, due in the first place to the great accuracy which may be obtained. Not only may large outputs of any given casting be produced by practically unskilled labour, and in a fraction of the time associated with sand working, but in the majority of cases all subsequent machine work is obviated, saving the cost of machine tools, drills, cutters, jigs, etc., and the expense of their upkeep and of skilled workers to operate them.

It is not intended to go very deeply into the technicalities of the various processes in general use, but a few notes on the aspect of this method of casting from the aluminium founder's point of view might not be without interest.

In both chill and die-casting more or less permanent metal moulds are used, usually of mild steel. In the one case the metal runs into the mould by its own weight; in the other it is forced in under artificial pressure. The mould is made up in several sections according to the intricacy of the part to be cast, a phase which in some cases involves no small ingenuity on the part of the designer. The mould is assembled, heated to the right temperature, the metal poured or forced in, and the various pieces of core and mould withdrawn almost immediately in their correct order. The process is then repeated as many thousands of times as required, the result being clean, bright castings of greater strength and homogeneity than may be obtained with sand working, and which in some cases turn out with a consistent accuracy to within ·003 in. The process has long been successful with other non-ferrous alloys, and the main difficulties met at first in the use of aluminium may be summed up as follows—

(1) High melting point (comparatively);

(2) Tendency of metal to absorb iron at that temperature;

(3) Relatively high shrinkage on cooling;

(4) Weakness at solidification point, particularly when overheated in melting.

Factors (1) and (2) limit the life of the moulds: cases have been known where moulds have lasted for 75,000 castings, but a more average figure is between 5,000 and 10,000. Also, in the case of die-casting there are two main systems of applying the pressure—

(1) By means of a mechanically worked plunger;

(2) By compressed air.

The tendency of aluminium to absorb iron discourages the use of casting machines incorporating an iron plunger, and the metal is best forced up into the dies by means of compressed air. The crucible is fitted with an air-tight cover, and is connected through a valve with a source of compressed air. By opening the valve great pressure is applied to the surface of the molten metal, forcing it through the nozzle into the interstices of the most complicated die. About 100 to 250 castings per hour may be turned out, and the quicker they are removed from the moulds the better, as the life of the die is affected if the metal remains long enough to cause much change in temperature. The dies may cost anything from £10 to £100, and the process would hardly pay were it not for the elimination of machining and the demand in certain industries for large numbers of castings of one design.

Factors (3) and (4) cause cracked castings unless the designer knows the characteristics of the medium he is working in. But nowadays most designers do thoroughly understand the possibilities and the limits of the metal, and any doubts as to the practibility of producing a certain part more economically by die-casting should be referred to one of the many competent firms specialising in the process.

Fig 13

SOME DIE-CAST ALUMINIUM PARTS

An interesting process for producing large thin-walled castings of more or less open shape is known as the Cothias, and is mentioned because it strikes a new note in die-casting methods. Briefly, the top and bottom of the mould are made in two separate units, the top half carrying the core. The exact quantity of metal is poured into the lower half which has been pre-heated to a given temperature, and the top portion is forced down into the other, making a metal tight joint and compressing the molten metal into every corner of the mould. The apparatus in action is not unlike an ordinary power press, but uses molten metal in place of sheet, with all the advantages in mobility of the former.

But that expensive and complicated machinery is not an indispensable adjunct was amply demonstrated to the writer on the occasion of a visit to a small chill-casting concern in the North of London during the war. Here were to be seen numbers of boys turning out with apparent ease and accuracy vast quantities of aluminium machine gun and aeroplane parts, using apparatus almost primitive in its simplicity.

The standard alloy used in die-casting consists of 92 per cent. aluminium and 8 per cent. copper, average tests of this material showing the following properties—

	Sand Cast.	*Die Cast.*
Tensile strength .	20,000 lb. per sq. in.	25,000 lb. per sq. in.
Elastic Limit . .	13,000 ,, ,,	13,000 ,, ,,
Elongation on 2 in..	1·7%	3·1%
Specific Gravity .	2·84	2·8

It will be noted, from this and a subsequent table of typical alloys suitable for chill moulds, that the castings from metal moulds show a superiority over those cast in sand. It should be mentioned that the properties of castings in metal moulds are affected if the metal is overheated. Aluminium absorbs nitrogen fairly freely when overheated: in sand moulds this is given up more or less as the metal solidifies, but in metal moulds solidification takes place before the nitrogen can escape from the metal, and in any case the nature of the mould does not lend itself to easy exit of gases. An overheated melt means generally a batch of porous castings, and obvious as the remedy may seem, in practice aluminium often becomes overheated owing to impatience on the part of the operator. The latent heat of fusion of aluminium is exceptionally high, and although a furnace may be of sufficiently high temperature to raise the metal to the melting point, actual melting will only occur when the charge has satisfied its abnormal capacity for heat. This takes time, and there is often a tendency to turn on more gas to expedite matters. There is a striking passage by Prof. J. W. Richards in his text-book on the subject, which is sufficiently interesting in this connection to quote in full—

" The high specific heat of aluminium compared with other metals and particularly its large latent heat of fusion, cause the metal to melt very slowly even in a very hot fire. As seen above, over 258 calories have to be absorbed in order to raise it to the melting point and melt it. It compares with other metals as follows:

Aluminium	258·3 calories
Cast iron	250·0
Copper .	162·0
Platinum	102·4
Silver .	85·0
Gold .	58·0

We can therefore deduce the interesting fact, which is amply confirmed by observation, that having a furnace hot enough to melt cast iron, we would find that a given weight of gold, silver or copper would melt before the same weight of aluminium, and even the cast iron would not be far from melting by the time the aluminium fused."

The full significance of this passage may be grasped by comparing the melting points of the metals referred to. This property in aluminium accounts for the seeming paradox of its employment with success in the chills for chill casting aluminium itself. Whether or no such chills are a commercial proposition cannot yet be stated, since they have up to the present been used only in cases where great accuracy was not of such importance as a large output. But the advantages found in such cases were the ease with which dies were made, any number being cast from one master, the fact that no iron was absorbed by the casting, and the saving on scrapped designs—the dies being melted and re-cast to a new form.

The following table gives some standard alloys suitable for chill moulds—

Al.	Cu.	Mn.	*Method.*	Yield Point.	*Ultimate.*	*Elongation.*
96%	4%	—	Sand	5·0 tons	7·5 tons	1·0% on 2″
96%	4%	—	Chill	5·5 ,,	9·5 ,,	2·5% ,,
94%	6%	—	Sand	6·0 ,,	7·5 ,,	1·0% ,,
94%	6%	—	Chill	6·0 ,,	10·0 ,,	1·5% ,,
90%	10%	—	Sand	6·0 ,,	9·5 ,,	1·5% ,,
90%	10%	—	Chill	6·5 ,,	11·5 ,,	2·5% ,,
96%	2%	2%	Sand	6·0 ,,	8 5 ,,	4·0% ,,
96%	2%	2%	Chill	6·2 ,,	9 0 ,,	5 0% ,,
95%	4%	1%	Sand	6·0 ,,	7·5 ,,	4·5% ,,
95%	4%	1%	Chill	7·0 ,,	10·0 ,,	5·0% ,

The foregoing notes are necessarily restricted in their scope and hardly do justice to so wide and interesting a subject. But they will have achieved their object if they leave the impression that the success of a light alloy in the foundry depends almost as much on foundry practice as on the analysis of the alloy, and that the enormous expansion in the production of intricate castings in aluminium alloys during the past few years has been attained only through the close co-operation of metallurgist, designer, and foundryman. In such

TABLE II

SOME TYPICAL ANALYSES OF LIGHT CASTING ALLOYS USED DURING THE WAR

% Alum.	% Copper	% Tin	% Lead	% Zinc.	% Iron	% Silicon	% Cupro Mang'ese	% Nickel	% Magne-sium.	Specific Gravity	Elas.	Ult. (tons)	Elong. on 2"	Brinell	Index Letter
91	7·0	1·0	—	1·0	—	—	—	—	—	3·01	3·60	6·24	2%	60	P
89·95	7·38	1·01	—	1·43	·14	—	—	—	—	3·02	3·2	5·32	1·9%	58	P
94·51	—	—	—	—	·16	—	—	5·18	—	3·00	3·0	5·01	2·02%	52	P
89·92	—	—	—	—	Trace	—	—	9·96	—	3·21	3·40	3·84	2·50%	63	P
91·0	7·0	1·0	—	—	—	—	1·0	—	—	3·01	5·44	6·08	2·2 %	58	P
90·0	7·0	1·0	—	—	—	—	2·0	—	—	3·01	4·76	5·2	2·0%	62	P
86·0	3·5	—	—	10·5	—	—	—	—	—	3·25	4·4	6·72	1·0%	62	P
87·0	2·5	—	—	10·5	—	—	—	—	—	3·18	3·84	6·72	2·0%	60	P
80·0	5·0	—	—	15·04	—	—	—	—	—	3·46	6·88	7·72	2·0%	72	P
75·27	6·89	1·96	·27	15·4	·08	—	—	—	—	3·51	6·70	7·2	1·5%	61	P
85·75	3·16	—	Trace	10·79	·21	—	—	—	—	3·24	5·28	7·6	4%	60	C
89·08	3·31	—	—	7·21	·15	·19	—	—	—	3·21	6·36	10·2	2%	62	C
92·26	2·20	—	—	5·21	Trace	·23	—	—	—	2·94	4·95	9·92	5%	55	A
89·51	9·66	—	—	·53	Trace	·21	—	—	—	3·22	7·8	8·75	2%	54	D
77·62	5·86	·28	·24	15·23	·68	—	—	—	—	3·53	6·8	7·48	2%	78	C
81·18	6·47	·68	·11	9·78	1·61	·14	—	—	—	3·40	4·2	4·56	2·1%	60	A
97·06	2·54	—	—	—	—	—	—	·12	·24	2·75	3·8	6·96	3·5%	45	O
75·95	5·49	1·65	·39	15·07	1·12	·23	Mn. ·10	—	—	3·09	5·08	11·08	4·0%	67	A
82·18	2·96	—	·12	13·95	·75	—	—	—	—	3·30	5·92	14·56	5·0%	74	A

P Specimens from Aero Engine Pistons in use
C „ „ Automobile Castings } Crank cases, Cylinders, etc.
A „ „ Castings for Aircraft }
D „ „ Die cast parts on Aircraft
O „ „ Ormiston Metal Cylinder Blocks

few cases where nature has endowed one man with all three attributes, there will be found the highest degree of excellence in casting work and the most advanced progress in the layout of plant.

LIGHT ALLOYS SUITABLE FOR ROLLING AND DRAWING.—Alloys of this class, as distinct from those recommended for casting, are to the present date headed by Duralumin, which is almost the only alloy so far known which is improved by heat treatment. An average analysis gives Al. 94·4, Cu. 4·5, Mg. 0·95, Mn. 0·76, but an alloy simply made up in these proportions will not give the physical properties found in Duralumin, which depend rather on its subsequent mechanical and heat treatment. Details of the process employed are, naturally enough, not readily available, but if the above alloy be heated and quenched, and then " aged " from 5 to 8 days, it will exhibit properties closely akin to those characteristic of Duralumin. Thus the alloy when simply taken and rolled gives a tensile strength of 17 tons per sq. in., with an elongation of 13·5 per cent., but if it is raised to 510° C. and suddenly quenched, and is then left to " age " for five or six days the tensile strength rises to 25·5 tons per sq. in., with a 19 per cent. elongation on 2 in. Since Duralumin averages 25–30 tons, with 13–15 per cent. elongation, it is possible that this is much the procedure followed. The alloy may be rolled and forged with ease, shows a remarkable resistance to corrosion, and is not readily affected by prolonged fatigue stresses.

It is widely used in aircraft construction, to a lesser extent in the connecting rods of the lighter rotary engines, and is a standard material in most situations calling for a weight hardly exceeding aluminium with a strength comparable with that of some steels.

Magnalium.—An alloy which may be cast or rolled,

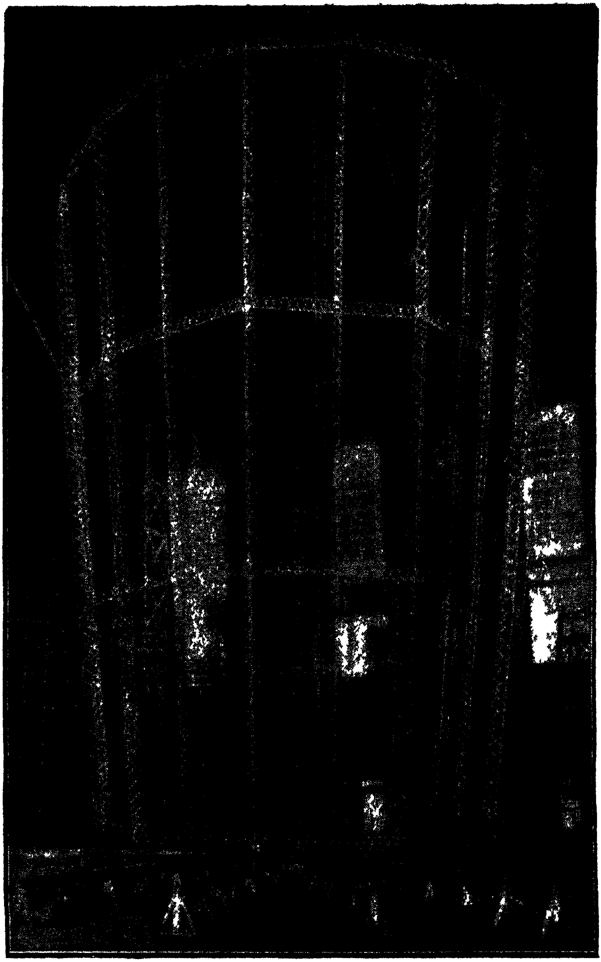

Fig 14

SECTION OF DURALUMIN FRAMEWORK FOR LARGE NAVAL AIRSHIP and is claimed to be rather lighter than pure aluminium. An analysis of a rolled specimen gave Cu 0·21, Mg 1·58, Sn 3·15, Pb 0·72, the balance being aluminium. This specimen gave a tensile strength of approximately 18 tons to the sq. in., but little information is available as to its properties under increase of temperature. There are numerous patented alloys of this class marketed under such names as magnalite, zimalium, etc., suitable for rolling and drawing, and for light constructional work generally. They mostly consist of aluminium with varying small proportions of copper, manganese, and magnesium, with an occasional percentage of tin. Additions of metals of high melting point, such as iron, manganese, nickel, etc., tend to improve the quality in an alloy to withstand high temperatures. The whole subject of light alloys has a peculiar fascination, and although a great deal of valuable work has been accomplished the art is as yet in its infancy. As an illustration of the hidden possibilities of research in this field, it is interesting to recall that the National Physical Laboratory recently carried out experiments on one of the British Aluminium Company's standard alloys supplied for casting purposes. It consisted of 77 per cent. aluminium, 20 per cent. zinc, and 3 per cent. copper, and when extruded at 395° C. and hot-rolled, this alloy gave a tensile strength of 25 tons per sq. in., with an elongation of 18 per cent. on 2 in. These results, which compare favourably with those of Duralumin, are of interest mainly because they were obtained with consistency from an ordinary standard alloy widely used for automobile and similar castings.

CHAPTER VI

HINTS ON WORKING WITH ALUMINIUM

STANDARD forms in which aluminium is delivered to the market include sheet, rod and wire, and a great variety of sections from the extrusion press. The methods of producing such forms follow much the standard practice obtaining with most non-ferrous metals, and need not be treated here. But in the preparation and working up of sheet and section, and in its manipulation into the diversity of shapes and structures in which the metal finds its applications in industry there are one or two characteristics in aluminium which are usefully borne in mind, and the following notes may therefore be of interest.

Machining.—Aluminium, particularly the pure metal, is soft and tough in machining and is liable to be torn or dragged by the tool. A pointed tool with a large top clearance is recommended, and as high a cutting speed as the nature of the work permits. There are many excellent lubricants for this purpose on the market, consisting generally of mixtures of bees-wax, turpentine and petrol, but the best all-round lubricant is ordinary paraffin oil, which has the advantage of being more universally available. Some machinists use turpentine, but it may be pointed out that this tends to evaporate and leave a resinous deposit on the work, which in the case of screw-threads is to be discouraged. Paraffin also evaporates, but leaves a deposit of the nature of vaseline, and screws are therefore not so liable to bind when machined with this lubricant. These remarks refer mainly to pure metal; no difficulty will be experienced in machining any of the standard alloys.

Spinning.—Aluminium is readily spun in the lathe on either metal or wood chucks. The softest sheet is used and is worked at speeds up to 3,000 ft. per minute, a good lubricant for the process being ordinary vaseline. The metal requires no specialised treatment in this operation, being probably easier to work than any other metal. The metal is hardened during spinning, and an article made from annealed sheet will be found to be almost dead hard when finished.

Pressing.—In the draw-press aluminium will stand up to more severe treatment than any other commercial metal. From a flat blank, a cylinder with a depth 75 per cent. or more of its diameter may be pressed in one operation, showing a high standard of ductility. Where, as in the case of such commodities as cooking utensils, lamp reflectors and fittings, etc., a spinning operation follows on the pressing, one press will keep a number of spinning lathes working all out to keep pace with its output.

Stamping.—No special treatment is required, the metal takes a deep stamp with no signs of pulling at the corners or roughening at the edge of the die. For all pressed and stamped work the softest grade of metal should be used. Sheets may be annealed in a muffle at a temperature of 750° to 900° Fah., according to the gauge of sheet. Ample time should be allowed to enable the metal to equalise its temperature throughout, a sustained heat treatment at a low temperature giving far better results than a quick operation at higher temperatures, and cooling should take place as slowly as possible.

Polishing.—Aluminium will take and retain a very high polish, and is treated in much the same way as brass and German silver. The articles are firstly sanded with ordinary Trent sand and oil on a bob covered with leather, running at high speed. The next operation is grease mopping, using tripoli compo and a calico mop, and finally the articles are finished off with a soft mop, using dry lime.

Satin Finishing.—A fine steel scratch brush running at high speed will give a very white satin finish to sheet metal. Light strokes are desirable, and the brush must be quite free from grease. Sheffield lime applied to the brush will remove any occasional splash of oil or grease from the machine. Sand castings may be polished by this method, and all sand, and discolorations caused by overheated metal effectually removed.

Frosting.—To give a fine white frosted appearance to pure aluminium, the metal should first be cleansed by washing in hot water or a weak solution of common potash. It should then be plunged into a 5 per cent. solution of caustic soda, which is maintained at a temperature just below boiling point, in which it should remain until the surface is blackened—usually a matter of a few seconds. The metal is then washed in cold water, and dipped in *aqua fortis* to neutralise the alkali, after which it is again washed in cold water. Finally it should be dipped in hot water and dried off in clean sawdust. If heavy frosting is required, to every 40 gallons of the above solution add a bucket full of common salt.

Riveting.—Provided attention is given to a few points of a practical nature, aluminium lends itself readily to riveting and no difficulty need be anticipated in making an efficient and lasting joint by this method. Excellent machine-made rivets of aluminium are available, and these should invariably be used in order to avoid future trouble from electrolytic action. Having in view the low yield-point of the metal, rivets must have ample clearance in the holes, and the holes should be spaced rather closer together and set further from the edge of the plate than is usual in dealing with other metals, or the metal may show an occasional tendency to bulge. For plates of from $\frac{1}{16}$ to $\frac{3}{16}$ a safe rule for the amount of lap is not less than 3½ times the diameter of the rivet, when dealing with single riveted lap joints. Owing to the softness of the metal and consequent spreading, the holes in the two plates may be found not to coincide after a few rivets have been hammered up. It is therefore advisable to insert temporary rivets or bolts at intervals along the joint before commencing the riveting proper, and this will be found to save a lot of unnecessary reaming. Aluminium rivets are too soft to be forced through the overlap, and where therefore holes do not entirely coincide they should invariably be reamed out. The type of rivet most commonly used is the ordinary cup-head, and the tail of the rivet should project about 1½ times its own diameter to allow sufficient metal to form a substantial cup-head by means of a snap-tool. Countersunk riveting is widely employed on automobile and railway car panelling, and in this type care should be taken that the angles of the rivet head and countersunk are identical. In some cases the countersink is formed by a special tool which works up the metal to form a heavy burr, and this is afterwards hammered down smooth over the rivet head, concealing all traces of the joint and rendering the use of beading unnecessary. In chemical and other industrial plant where aluminium is rapidly taking up a pre-eminent position by reason of its non-corrosive properties, the cup-headed rivet is almost invariably used in such few cases where the joint is not autogenously welded, and for this and similar work the rivets are spaced more closely to ensure a watertight joint. If a slight leak should occur, caulking or fullering may be resorted to as with other metals.

In the riveting of aluminium there are therefore the following points for special attention—

Provision of a liberal overlap.

Close spacing of rivets.

FIG. 15

RIVETED TANK OF ALUMINIUM USED BY BLEACHERS FOR TRANSPORTING CLOTH BETWEEN DEPARTMENTS

Placing of these well in from the edge of the plate.

Provision of liberal clearance in the holes.

Getting these to exactly coincide before trying to rivet.

Finally, in dealing with this light metal, many light blows are preferable to a few heavy ones.

Soldering.—So much has been written on the soldering of aluminium, and so many claims put forward either to remain unsubstantiated or to be subsequently disproved in practice, *that an entire volume might be* devoted to this subject without arriving at any definitely satisfactory conclusion. Experience gained during the past decade, however, goes to prove at least these three points—

(1) That aluminium can be soldered.

(2) That the process is rather more troublesome than is the case with other metals.

(3) That the number of fluxes and solders at present on the market which will give a permanently sound joint is extremely limited, despite the perennial influx of specifications dealing with the subject.

The main obstacles to an easy and permanent soldering process may be summed up as follows—

(1) The refractory oxide film, which is intensified at soldering temperatures, and prevents the efficient interfusion of the metals.

(2) The thermal conductivity and high specific heat of aluminium renders local heating to the alloying temperature a tedious operation, more particularly in heavy work.

(3) Last, but not least, the highly electro positive nature of the metal causes galvanic action to be set up with most of the alloys which are practicable on the score of low melting point. Thus an apparently perfect joint may, owing to internal electrolysis, disintegrate within a comparatively short period.

On the other hand, there are undoubtedly solders on the market which give good results, particularly on those jobs which, owing to environment or working conditions, are kept entirely free of moisture, or may be painted over with a waterproof enamel. The various patented compositions of both solders and fluxes are too numerous to deal with in detail, but for the most part the former are made up of aluminium, tin, and zinc in varying percentages, with the occasional addition of small quantities of phosphor tin, silver, antimony, vanadium, etc. A solder commonly used consists of 80 per cent. tin, 2·25 per cent. aluminium, 17 per cent. zinc, and 0·75 per cent. phosphor tin, while another is made up of tin, aluminium, cadmium and magnesium in the proportions of 85·10, 10·8, 1·35, and 2·75 per cent. respectively. These two, selected at random, are fairly representative of an immense list of formulae, ranging from the simplest alloys of tin and zinc to specifications of sufficient length to qualify them for a registered trade title. The same remarks apply to the fluxes. The object of the flux is to dissolve with the solder without chemical hindrance, and if this object has yet been attained the fact remains that the best and most lasting results are still obtained with the assistance of mechanical abrasion. In the following procedure quick manipulation is necessary.

1st. Clean off all dirt and grease from the surfaces with a little benzine.

2nd. Apply the solder with a copper bit, and while it is still molten and covering the surface of the metal, scratch through the solder with a wire scratch brush. This effectually breaks up the oxide on the surface of the metal underneath the solder, and the latter takes up the oxide and renders tinning of the aluminium surface possible. When the aluminium has been efficiently tinned, the soldering operation is straightforward and comparatively easy. Solders are often made up in sticks containing a suitable flux, such as stearin, in the right proportions, but those containing phosphor tin may be satisfactorily worked without the assistance of a flux, owing to the affinity for oxygen characteristic of phosphorous.

A soldering bit of pure aluminium is strongly recommended in some quarters as being preferable to one of copper, on account of the tendency of the latter to alloy with and discolour the joint. The lower melting point of aluminium, however, must be kept in mind in using a soldering bit of this metal, and correspondingly greater care exercised in the heating. The flame of the blow-lamp should be as free as possible from free carbon, and a large blow-pipe flame should only be employed in pre-heating the parts to be soldered—not on the solder itself.

Any intelligent operator can produce an absolutely sound joint in aluminium by soldering, with the aid of patience, quick manipulation, and thorough cleanliness, but it is perhaps not overstating the case to remark that not one out of ten can guarantee that the joint when made will remain permanently sound. A convincing test is to boil such a joint for an hour or so in slightly salt water; there are solders which will stand up to this treatment, but they are few, and the few that do have been known to fail under the test of time. The A.E.G. firm have overcome this difficulty in the case of winding armatures, transformers, etc., with aluminium, by copper plating the parts to be joined and then soldering in the usual way, and they have brought this practice to a high degree of development. In view however, of the ease with which aluminium may be autogenously welded, the success or non-success of soldered joints as a factor in the development of the general utility of the metal, carries less significance than might otherwise have been assigned to it.

Autogenous Welding, or Autogenous Soldering, as it should more logically be named, has only been applied to aluminium since 1900, but the immense strides made in aluminium construction since its introduction are sufficient tribute to the efficiency of the method. The system as seen in lead-burning is of considerable antiquity, and it had for some time been recognized that a joint in aluminium containing nothing but aluminium would be entirely free from galvanic action, and would unite the parts into one homogeneous whole which should be no more liable to breakage or leakage at the weld than at any other portion of the work. In other words, no joint proper would exist at all, a condition essentially more satisfactory than any riveted, bolted, or seamed joint, however carefully made.

Initial difficulties, however, existed with regard to the removal of the persistent film of oxide, the melting point of which is in the neighbourhood of 3,000° C. Credit for the introduction of a practical lasting joint must be ascribed to Messrs. Herans, in Hanan, near Frankfurt. By their process the two carefully cleaned aluminium parts are laid together and, by means of a blow-lamp, raised to a temperature exceeding 400° C., but below the melting point. The two portions are then hammered together or united by means of a rolling mill, and any slag or oxide is squeezed out, the process being analogous to the Butt welding described in a later section. The joint thus formed is of pure aluminium and mechanically sound, but the application of the method is necessarily limited to such forms of the metal as are not likely to be damaged by hammering or rolling during the cooling process. The method is interesting, both from an historical point of view and from the fact that it is a form of true welding, but it has been entirely superseded by the oxy-acetylene process.

The first practical method for dissolving the oxide film and allowing the metals to flow together is described by Schoop in German patent No. 222960, which with several supplementary patents is the property of the Akt. fur Autogene Aluminiumschweissung of Zurich.

The specification describes a composition comprising 60 parts calcium chloride, 12 parts sodium chloride, and 4 parts calcium sulphate, and the patent covers all fluxes consisting of a mixture of alkaline chlorides in fluid, semi-fluid or powder state. A later patent (No. 224284), taken out in Switzerland by the same inventor, covers the use of the alkaline bromides and all the halogen compounds as reducing agents in aluminium welding. The various combinations of alkaline chloride, fluorides and bromides comprise practically the only means of fluxing aluminium welds with any facility, and a flux much in use for this purpose consists of—

Sodium Chloride . . .	30%
Potassium Chloride . .	45%
Lithium Chloride . .	15%
Potassium Fluoride . .	7%
Sodium Bisulphate . .	3%

The most economical method of using the flux, and one which gives very good results, is to apply it to the joint in the form of a varnish on the rod. The end of the welding rod is heated and dipped into the flux, which will adhere to it in the form of a small tuft. This should be melted along the rod giving an even coating about 6 in. long. It should then be unnecessary to apply further flux to the weld, the gradual melting of the rod giving a steady supply at a rate proportionate to the speed of welding. The practice of dipping the heated end of the rod at intervals and completing the weld, as it were, in sections, is not recommended. It is liable to cause flux inclusions at some points and inclusions of oxide at others, and cannot tend to the formation of an ideal, homogeneous weld.

The heat of the flame is adjusted to suit the character of the work. On very thin gauges the oxy-acetylene flame is liable to go straight through the plate, and oxy-coal gas or oxy-hydrogen is sometimes employed. The use of the lower temperature gas mixtures, however, is to be avoided as far as possible. They contain a high percentage of water vapour which tends to cause pinholes in the weld, and they are necessarily slow in action and give too much opportunity for oxide to form and be included in the joint. Oxy-acetylene is invariably used on the heavier plates. The edges should be thoroughly cleaned and bevelled off at an angle to one another; they are then butted together leaving a space generally taken as equal to the gauge of the plate. The flame is then brought to bear on the parts, and under the influence of the high temperature these flow together in a remarkable manner, forming a permanently reliable and homogeneous joint. In practice it is usual to feed in new metal either with a stick of aluminium, or a composite stick of aluminium containing a core of flux. This latter practice is not recommended: a stick of the metal of the same analysis as given by the parts to be welded is always preferable, and this should be dressed with flux as described above.

Cases have been reported to the author where a welded joint has shown under test an abnormal brittleness. These are comparatively rare, and may be attributed to the use of impure materials, or metal containing an excess of silicon and iron, or more probably, the use of an excess of flux.

By hammering the weld with firstly a hardwood mallet, and afterwards with an ordinary hammer, and by gently re-heating the whole to 450°–500° C., the homogeneity of the weld-zone is much improved, and the physical effects due to rapid local heating, fusing, and sudden cooling, are considerably modified. Care should be taken to confine the action of the flame to the joint alone, and in the thinnest plates it is advisable to

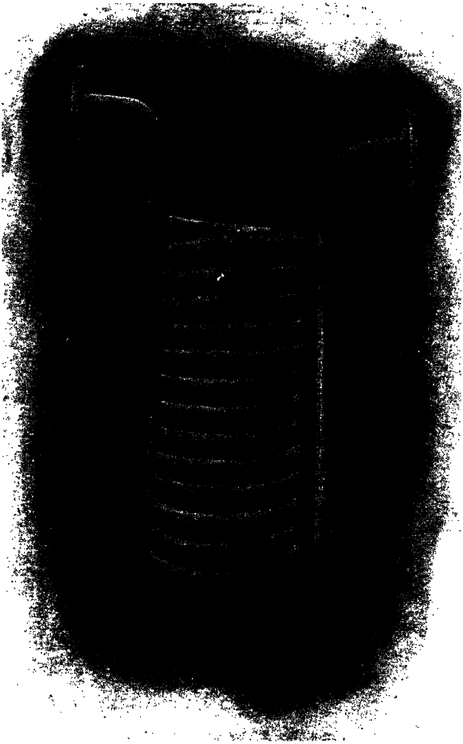

Fig. 16

SEAMLESS CONDENSER COIL, OF AUTOGENOUSLY WELDED ALUMINIUM arrange for some sort of thermal buffer, such as a clamp of copper, which will conduct away any superfluous heat from the parts adjacent to the joint and thus prevent any accidental burning.

Aluminium welding, like so many operations connected with the metal, suffered unnecessarily from secrecy during the early days. There is little secret in the process. Any man of average intelligence, without any previous experience in the handling of the blow-pipe, can produce passable welds in aluminium within an hour's tuition, while a practical welder of other metals should have no trouble at all in turning out consistently good work, provided he watches the following points—

(1) Use correct size of blow-pipe for the work.

(2) Adjust blow-pipe carefully to give neither an oxidising nor a reducing flame. Do this by adjusting the acetylene cock, not by varying the oxygen pressure, which must remain at that for which the blow-pipe was designed.

(3) *Keep the white conical part of the flame well away from the weld.*

(4) Clean edges of weld, *and the welding stick,* of all traces of grease or oil.

(5) Use neither too much nor too little flux—the varnished rod gives best results.

(6) Keep the end of the rod continually in the molten bath while welding. Do not try to break up the oxide by "puddling," but rely wholly on the action of the flux.

(7) Pre-heat large work. Contraction and expansion stresses cause the highest percentage of failures in repair of castings.

(8) After welding, thoroughly scrub the weld with warm water to remove the excess of flux, which will otherwise corrode the work.

Finally, the main difference in the manipulation of aluminium as compared with steel, lies in the fact that the speed of welding rapidly rises when welding a long seam, owing to the great thermal conductivity of the metal and the consequent rise in temperature of the whole job. Once this is realised, the troubles of a beginner are cut down by 50 per cent.

TABLE III

SOME ANALYSES OF FLUXES IN USE FOR WELDING ALUMINIUM

Constituent.	*Percentages.*								
	1	2	3	4	5	6	7	8	9
Sodium Chloride .	30	12·5	6·5	—	16	17	79·2	—	12
Potassium Chloride	45	62·5	56	33·3	79	83	4·2	62·5	60
Lithium Chloride.	15	20·8	23·5	33·3	—	—	7·4	—	24
Calcium Chloride.	—	—	—	—	—	—	—	31·3	—
Sodium Fluoride .	—	—	—	33·3	—	—	—	—	—
Potassium Fluoride	7	—	—	—	—	—	—	—	—
Cryolite . . .	—	—	10	—	—	—	9·2	6·2	—
Potassium Sulphate	—	—	—	—	5	—	—	—	—
Potassium Bisulphate . .	3	4	—	—	—	—	—	—	4
Sodium Sulphate.	—	—	4	—	—	—	—	—	—

CAST WELDING OR BURNING.—This system has its uses in repair work to small castings, etc., and is employed mainly in connection with fractured crank-cases and gear-boxes of automobiles. It is essential to good work to set up the fractured casting in a carefully prepared mould, in which the parts are firmly secured in order to avoid as far as possible any distortion during pouring. Provision must be made for the initial pouring to flow out by suitable gates, after passing over and heating to fusing point the surfaces to be welded. Tall "headers" must be provided to supply sufficient pressure to penetrate the oxide film, and to receive the dross formed during the pouring operation. A stream of metal is then kept running into the joint until the parts actually fuse together, no opportunity being given for new oxide to form.

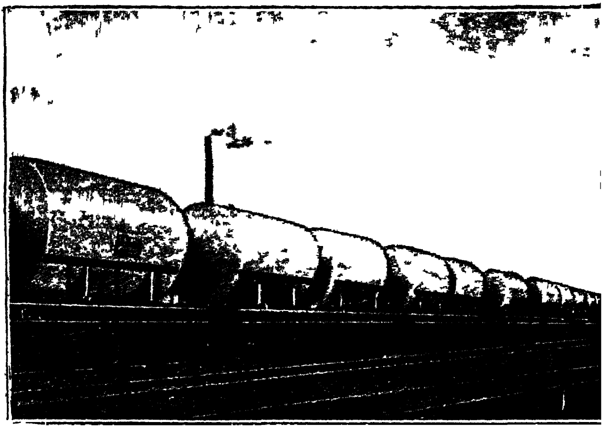

FIG. 17

A TRAIN OF WELDED ALUMINIUM STORAGE TANKS

The main disadvantage of this method is the liability of the parts to warp, necessitating careful handling and also careful setting on completion. But many thousands of complicated repairs have been carried out in this way with complete success, and there is little doubt as to the efficiency of the joint when formed.

Provided such points as those touched on in this chapter are kept in view, no difficulty will be found in working with aluminium. The metal is essentially a clean and facile medium to work in, light to handle, and strong for its weight: the key to its success in any given application lies in an intelligent appreciation of its possibilities and its limitations. In bringing this section to a close the author feels that no thoughtful balance of words could so happily sum up the situation as those written by St. Claire Deville in 1859, which are as appropriate to-day as they were sixty years ago—

"I have tried to show that aluminium may become a useful metal by studying with care its physical and chemical properties, and showing the actual state of its manufacture. As to the place which it may occupy in our daily life, that will depend on the public estimation of it and its commercial price. The introduction of a new metal into the usages of man's life is an operation of extreme difficulty. At first aluminium was spoken of too highly in some publications, which made it out to be a precious metal, but later these estimates have depreciated even to the point of considering it attackable by pure water. The cause of this is the desire which many have to see taken out of common field mud a metal superior to silver itself, while the opposite opinion established itself because of very impure specimens of the metal which were put in circulation. . . .

"The industry, established as it now is, can be the cause of loss to no one."[1]

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[1] *De L'Aluminium*, 1859.

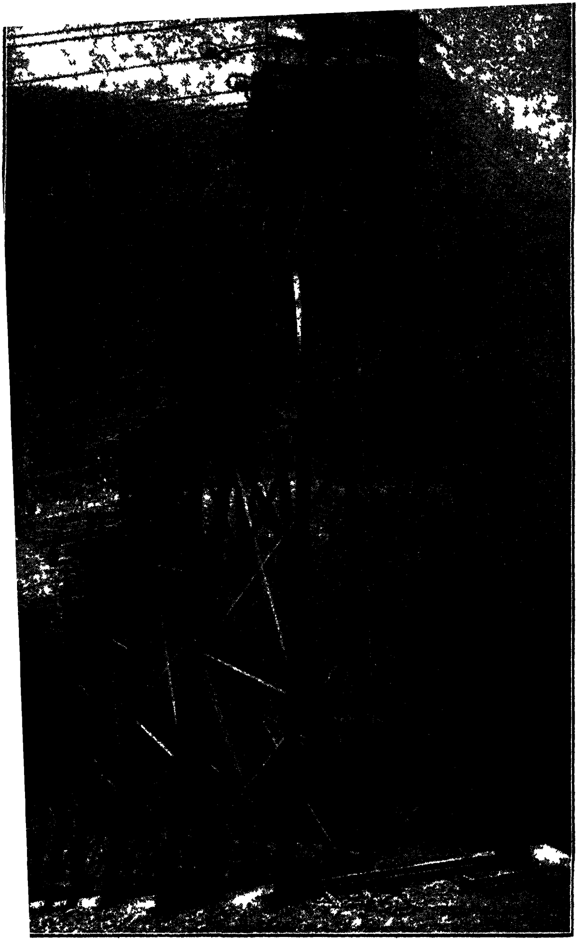

FIG 18

NE OF THE LARGEST POWER TRANSMISSION SCHEMES
THE WORLD. TWENTY THREE-PHASE CIRCUITS,
RRYING OVER 150,000 K.W. AT 10,000 VOLTS, WITH
ALUMINIUM CONDUCTORS

PART II

APPLICATIONS

CHAPTER VII

If this book had as a subject one of the more widely known metals, this is the point at which it would logically come to a conclusion, with a chapter or so on statistics, an article on its uses and abuses in the Great War, and possibly an appendix on prospects during a long and precarious peace. Considerations of the commercial applications of the metal would have been conspicuous chiefly by their brevity. The applications of iron, copper, tin, etc., are too well known to merit more than passing reference, the space being better reserved for the methods of extracting these historically ancient metals, which are complicated by a variety of processes demanding ample elucidation, if they are to be grasped with any comfort by the normal reader.

But in the case of aluminium the position is reversed. There is only one method of production in use, and it is very quickly and simply described, while on the other hand the average man's knowledge of the capabilities of the metal seldom extend beyond his kitchen or the dashboard of his car. He may indeed retain the shape of his shoes with aluminium "trees": he may be dimly aware that the fittings to which he clings in his subterranean passage citywards each morning are of aluminium, because these are thrust painfully upon his attention at intervals: he may even endorse his cheques with an aluminium pen. But for the most part the inroads of this metal into the highways and bye-ways of industry are to him a closed book.

"Aluminium may be used in practically every situation now employing copper or brass." This is in brief the reply generally vouchsafed to casual inquirers, and while it is broadly true it is misleading. For there are several situations where aluminium could not be very efficiently substituted for copper or brass, and on the other hand there are important fields in industry wherein some peculiar property in the light metal recommends its employment to the exclusion of all other materials. As an example of the first case which will come home to everyone, the household linen has from

FIG. 19

AN ALL-ALUMINIUM BODY BY PORTHOLME MOTOR WORKS time immemorial been boiled, steeped, and otherwise cleansed in a "copper": an aluminium cauldron would cost less, but would be an ill-advised innovation because the rites demand the use of soda, and soda is anathema to aluminium. But on the other hand, should a man desire to build a zeppelin or cook an omelette, to transmit 40,000 horse-power 400 miles, or to blow up the Albert Memorial, it is probable that he would find in aluminium a medium in which to express his inspiration, because of some property in the metal which is partly or wholly absent in other common metals.

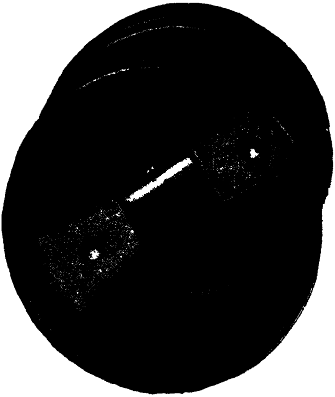

FIG. 20

ALUMINIUM "AEROLITE" PISTON

It is to assist in a proper understanding of these properties that this section has been written: to describe what has been done with aluminium and why it was done, and to leave with the future what may yet be done, with the assistance, maybe, of the discriminating enterprise of the reader.

A broad review of the applications of this metal will show that they may be conveniently grouped into three chief classes, according to whether those properties which led to any individual application were of a mechanical, or a chemical, or an electrical nature.

TABLE IV

MECHANICAL

PHYSICAL AND MECHANICAL PROPERTIES OF BRASS, STEEL, AND ALUMINIUM

Property	*Brass*	*Steel.*	*Aluminium*
Melting Point, °C. . .	950	1,400	655
Melting Point, °F. . .	1,740	2,550	1,210
Annealing Point, °C. .	500	760	400–480
Annealing Point, °F. .	868	1,400	750–900
Specific Heat (Water = 1)	0·094	0·117	0·212
Thermal Conductivity (Silver = 100)	23·8	11·7	31·3
Coefficient of Linear Expansion, per °C. . .	0·0000189	0·0000120	0·0000234
Coefficient of Linear Expansion, per °F. . .	0·0000105	0·0000067	0·0000130
Specific Gravity, Cast .	8·10	7·73	2·60
Specific Gravity, Rolled .	8·62	7·74	2·67
Weight in lbs. per cu. in., Cast	0·294	0·280	0·0944
Weight in lbs. per cu. in., Rolled	0·313	0·281	0·0969
Tensile Strength in lbs. per sq. in. ,Cast. . .	18,000	70,000	13,000
Tensile Strength in lbs. per sq. in. Rolled . .	22,400	115,000	20,000
Elastic Limit as % of Tensile Strength . .	38	66	60
Modulus of Elasticity in lbs. per sq. in. . . .	9,200,000	30,000,000	9,000,000

A high proportion of the world's output of aluminium is absorbed into the construction of modern automobiles and aeroplanes and their prime movers, great advances having taken place in this direction during the war. In the case of aeroplanes, the cowlings, fairings, instruments and some of the pipes and fittings were the first steps in the use of the metal, but latterly either aluminium or its alloys began to show in some designs as stream-lined struts and internal wing bracings, and even in some cases was extended to the whole wing. The main object was, of course, lightness for strength, but for war purposes the fire-proof nature of the material afforded almost as potent a reason for its adoption, and also the fact that under the severe stresses of aerial combat an all-metal plane was considered more likely to retain its aerodynamic qualities without continual re-rigging. The end of the war saw the all-metal plane still in its infancy, but the results obtained by Messrs. Vickers and the "Bristol" firm had at least shown the possibilities that lay in developments along these lines.

In the case of the larger, lighter-than-air, craft the alloy Duralumin of course predominates throughout the whole design, and is largely responsible for the successful development of this form of aerial navigation. Practically the whole of the gigantic frame-work, a miracle of light-weight engineering, is constructed in alloys of aluminium, while the cars to carry the crew and the various power-units are largely built of this metal. The same reasons underlying its adoption to so marked an extent in this field, essential lightness for a given strength combined with a certain facility in working, may be applied to its rapid acceptance in the automobile industry where lightness on tyres and economy in fuel are becoming controlling factors in the choice of a car. The panelling and body-work generally have been of sheet aluminium for some years: it is easy to work into the desired lines, stands up to the work well, and gives a useful economy in paint for any given grade of finish. Lately the whole body has been cast in sections by the Pierce Arrow Company, the sections being bolted together and the whole bolted to the chassis, no separate framework or bracing being required. This practice has many advantages claimed for it: it certainly demonstrates in a remarkable manner the possibilities of aluminium foundry work. Dashboards, running boards, crank cases, gear-boxes, etc.,

FIG. 21

AUTOMOBILE BODIES OF ALUMINIUM CAST IN SECTIONS FOR THE PIERCE ARROW CO.

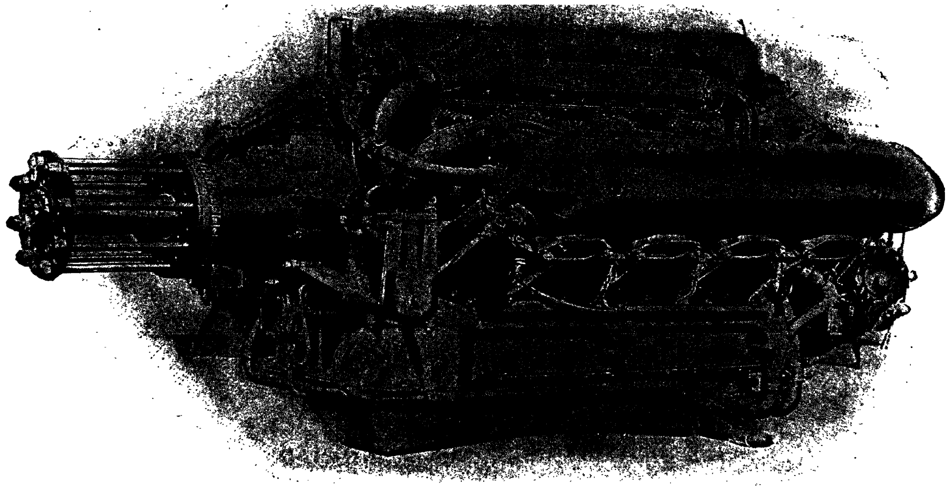

FIG. 22.
ALUMINIUM CASTINGS ON A 12-CYLINDER NAPIER ENGINE

are almost universally of aluminium, and call for little comment; it is in the engine that the most interesting metamorphosis is taking place. The experience gained during the war in the success of the Hispano Suiza aero engine, in which cylinders and pistons of cast aluminium alloy were outstanding features in the design, was followed up in the production of the B.H.P. engine, the Napier "Lion" and the modern Sunbeams. The success of these engines lay not so much in the phenomenally low weight-power ratio—the Napier weighing but 1·8 lb. per horse-power—as in their capacity for quick production resultant on the extended use of castings in place of welded steel construction and the elimination of a great deal of intricate machining. Another important factor in their success was undoubtedly the high thermal conductivity of aluminium, which enabled unusual mean effective pressures to be realised without serious overheating.

As an example of this aspect, a steel piston may be made as light or even lighter than one of aluminium, but with the high effective pressures now in use the heat generated in the combustion chamber and communicated to the crown of the piston, will not be conducted to the cool walls of the cylinder so rapidly as with aluminium. A limit is, therefore, set to the bore and the compression ratio of an engine employing steel pistons, which limit is considerably modified in the case of aluminium, for not only is the thermal conductivity *per se* of the latter metal higher than that of steel, but for the same weight there may be a greater body of metal in the crown to absorb and conduct away superfluous heat. The point is demonstrated notably in the Napier engine, in which an unusual ratio of bore to stroke is employed: it is doubtful whether a steel piston of equal weight would work for long in these engines, and it is certain that the use of aluminium pistons has a direct bearing on the high effective pressures realised. The experience on aircraft engine design thus gained cannot be without its effect on automobile policy with the coming of peace: automobile designers have for a long while incorporated aluminium pistons in their engines, and there are a number who are now basing their future policy upon the use of aluminium cylinders cast *en bloc*.

FIG. 23

MODERN AUTOMOBILE ENGINE IN CAST ALUMINIUM

It is a noteworthy fact that, with the classic exception of the Mercedes welded steel construction so highly developed by Messrs. Rolls-Royce, practically all outstanding advances in mass design in the petrol motor have been accompanied by an extended use of aluminium. The high thermal conductivity of this metal, its specific heat, and unlooked-for powers of radiation, were the object of special research during the war, and the results in air-cooling observed by the writer at Farnborough and his experience with the Bentley engine, incline him to a view which he has heard expressed by many designers during the latter months of the war. Namely, that the automobile engine of the future may develop along air-cooled lines, with cylinders and pistons of cast aluminium alloy; while recent experiments in the case-hardening of this metal may possibly result in the abandonment of a steel liner for the wearing surfaces.

FIG. 24

ALUMINIUM SIDE PANELLING

The same reasons which led to the use of sheet aluminium in automobile body-work, account for its adoption by many leading railway concerns in the panelling and ceilings of their passenger coaches: an appreciable weight economy, a saving in painting, and a resistance to fire and any sort of corrosion. This glass-like freedom from corrosion which characterises the metal now available to commerce was not in earlier times so consistent a feature: the application of aluminium to boat-building was not a success, and its non-success was doubtless in some degree due to impurities in the metal. Aluminium containing undue percentages of silicon or iron is certainly readily attacked by sea-water, and ill-chosen alloys of this metal are still more liable to deterioration, particularly in the cast state. In this connection, also, the high position of aluminium in the electro-chemical series must be taken into account (Table VI). In the presence of moisture, particularly of a saline nature, any contact with metals of different status in the series leads to electrolysis which may be of a negligible character or the reverse, and in the art of ship-building it is not always easy to arrange for consistent insulation of plates and accessories. On the other hand, the alternate exposure of modern sheet and rod to wind and tide has an effect which is inappreciable until another metal is introduced amongst the test pieces, and it would be interesting to learn how the fittings and castings on hundreds of sea-planes stood up to their work during the war, and what steps were taken to avoid corrosion.

The above general remarks indicate the chief paths along which aluminium has advanced into commercial use by merit mainly of its mechanical properties. There are many isolated examples of applications, such as the casting of belt pulleys on large planing machines in this metal to reduce the momentum and the wear in belts, and there are also the myriads of small fittings and accessories which confront one everywhere, the detailed consideration of which is somewhat beyond the scope of this little book.

CHAPTER VIII

IN THE CHEMICAL INDUSTRY AND ALUMINO-THERMICS

THE applications of aluminium from a chemical standpoint may be said to start at home with ordinary culinary operations. The microcosm is a copy of the macrocosm, as the theosophist cult helpfully remarks, and cooking is a chemical process which, when extended in scope and organization, forms a good proportion of the large chemical industries of this and other countries. Cooking with aluminium utensils is rapidly becoming universal, and need not be enlarged upon here, beyond the quotation of an interesting abstract from the *Lancet* of January, 1913—

"We are confident," so the author sums up his case, "that aluminium, as it is now made by reputable manufacturers, is a suitable material for cooking vessels, and that any suspicion that it may communicate poisonous qualities to food in the process of cooking may safely be dismissed in view of the results of the practical experiments which we have recorded, showing that the metal is not appreciably acted upon in cooking operations. This finding is satisfactory also, inasmuch as aluminium is an excellent heat conductor: cooking in aluminium vessels is therefore rapid, and fuel is economised in consequence. But the management of aluminium cooking utensils requires the same ordinary applications of common sense as are customary in the case of other metals employed for a similar purpose."

In view of the present-day ubiquity of the metal in the kitchens of most countries, it may seem somewhat surprising that a statement of this nature was

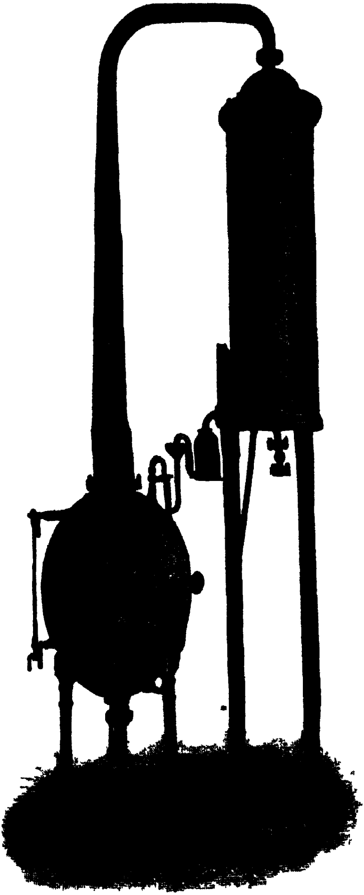

FIG. 25

BENZINE STILL FOR DIRECT OR INDIRECT FIRING apparently deemed desirable only six years ago. That it was so may hardly with justice be placed to the account of the metal itself, although it is possible that inferior metal may have been circulated in this, at that time, comparatively unimportant sphere of utility. It is possibly more traceable to the influence of other interests. " The introduction of a new metal into the usages of man's life is an operation of extreme difficulty." If a man has spent his life in building up a business in copper milk boilers or enamelled porringers, it is doubtful whether he would watch the advance of a competing material with any great enthusiasm. He would be hardly human if he helped to ease the difficulties in its path: conceivably he might try to add to them. At all events, aluminium in the early days of its application to cookery did not entirely escape the bane of unbalanced criticism, and its success in the face of this in establishing itself as a desirable factor in domestic economy, accounts in no small degree for its rapid adoption in the greater field of the chemical industries.

If you ask a cook why she uses aluminium in her kitchen, she will probably reply that it looks so nice and clean. It is more than that—it *is* clean, chemically, and it is also light to handle. Just such qualities as these are required in the big jam-making industries, in breweries, sugar and margarine refineries, and in the manufacture of the finer syrups and essences; in any enterprise, indeed, demanding a high degree of purity in the final product. Given a certain ease of construction and a reasonable economy in first cost, the adoption of any material meeting these requirements could be logically foreseen.

Aluminium as supplied to commerce is unaffected by organic acids and secretions, its salts are colourless and non-poisonous. It is attacked by hydrochloric and hydrofluoric acids, halogen solutions and caustic alkalis, but if it is not brought into contact with any of these it is suitable for a considerable range of chemical processes. The early difficulties in the establishment of large plant have been met largely by the agency of oxy-acetylene welding, and to-day the construction of complicated apparatus of great capacity is a standard departure in industry, employing the activities of a

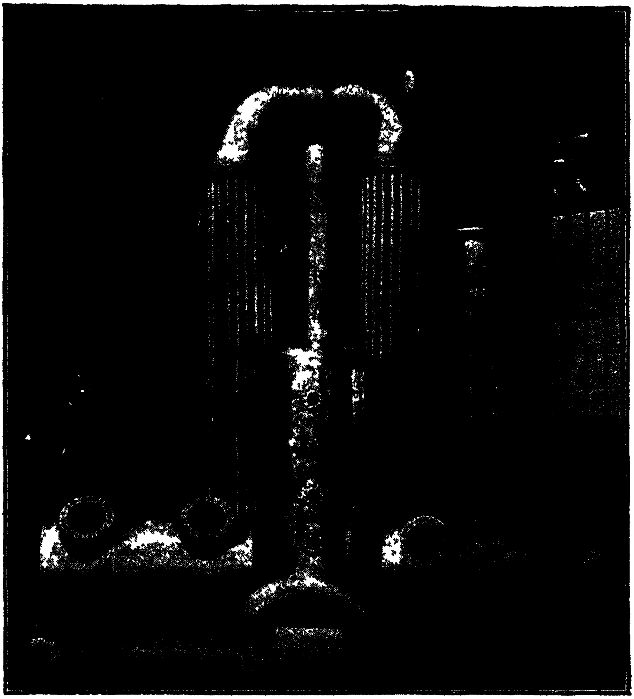

FIG. 26

ALUMINIUM CONDENSERS AND CHEMICAL PLANT

number of specialised firms. As built up by autogenous welding, aluminium vessels, condenser coils, etc., may be completed as in one piece: there are no joints or crevices to harbour dirt and micro-organisms as there were in earlier rivetted construction; the surface is smooth, non-porous and easily cleaned, and there is no danger of leakage.

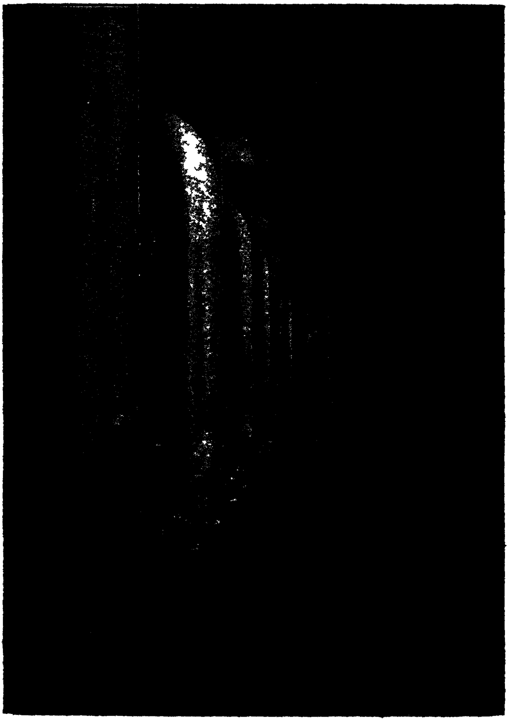

FIG. 27

ALUMINIUM STORAGE TANKS

One of the first big industries to adopt aluminium to any great extent was that of brewing, where the metal has been in use for some time in the construction of fermenting tuns, storage tanks, racking tanks, etc. The writer knows nothing of brewing, but has gathered the following grounds for its employment here. A new wooden vessel has few rivals for fermentation purposes, but it has one commercial drawback in the ease with which it becomes porous and harbours septic matter, which postulates fairly frequent and costly cleaning and sterilising. Aluminium, like wood, is clean to start with, but it is stated to be more easily kept in this condition. Tin as a substitute for wood is said to impair the brilliancy of beer and iron to give it an unpleasant taste. The same remarks may broadly be applied to the great range of foodstuffs generally, for which industry hundreds of tons of aluminium are supplied annually: the useful points being that the metal is easily handled, has a good thermal conductivity, and that its salts are non-toxic, tasteless, and colourless.

Aluminium is used to an appreciable extent in the varnish industry. According to an article in the *Oil and Colour Trades Journal* of February, 1913, its substitution for copper and iron occurred in the first place because, unlike either of these, it did not discolour the product. The ideal aimed at in the industry is the production of clean varnishes, as pale as possible, and of course as cheap as possible. If the varnish becomes discoloured during manufacture, the difficulty is allowed for by the use of only the finest gums obtainable. But on the other hand, if the use of aluminium means that the colour of the product is unaffected, it will be seen that any given shade of varnish may be made from a cheaper gum. This fact, taken together with the resistance of such vessels to the corrosive action of furnace gases, and consequent long life, would account for the adoption of the metal by the many firms now using it. The resistance to furnace fumes referred to, particularly fumes containing sulphur and its compounds, is one of the useful assets to the credit of aluminium.

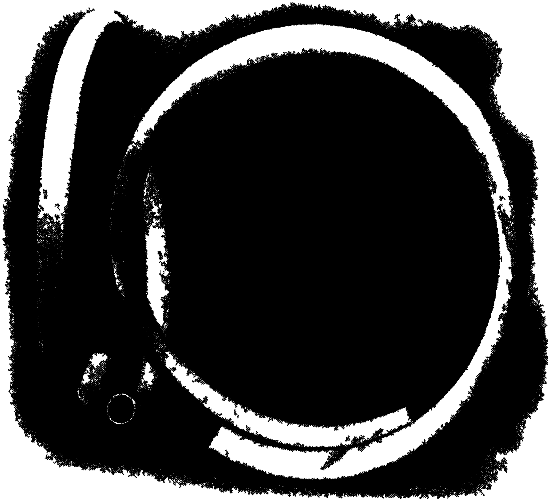

Fig 28

ALUMINIUM MANDRILS FOR INNER TUBES

There are many situations in and around gas works, coke ovens, destructor plants, and kindred concerns, where this metal is employed because of the above quality, on electrical cables and leads, condensers, and varieties of fittings, and even in some cases in the roofing in place of corrugated iron. Another industry which takes advantage of this property is that concerned with the treatment and vulcanising of rubber, the tyre industry in particular absorbs large consignments of aluminium in the form of tubular mandrils for inner tubes and the moulds for covers.

Stearic and palmitic acids have less corrosive effect on this metal than on any material which may be commercially employed on any scale, and even hot oleic acid is stored in aluminium tanks with safety. This immunity from attack by stearic acid in particular has turned the attention of soap and candle manufacturers to the possibilities of the metal, which is used with good results in a few applications in this industry, one of its chief recommendations being its freedom from the formation of verdigris, which is inseparable from the use of copper or brass.

Aluminium is slowly attacked by nitric and sulphuric acids, but stands up to the combined or separate effects of these acids better than the majority of commercial metals, and during the war was widely used in the nitrating pans and various accessories to the manufacture of explosives.

The foregoing are some of the better known chemical applications of aluminium which take into use any considerable tonnage of the metal. A number of others might be mentioned, but the object of this section is rather to indicate broad lines of development than to enter into tiring detail, and any expansion on these would merely confuse the issue. It would be of doubtful value to the reader, for example, to be assured that—

" Lakes of great fastness to light and purity of colour contain in combination a basic dye, *e.g.*, an alkylated dehydrothiotoluidine, aluminium, and either a polyhydroxyanthraquinine colouring matter, or an aminohydroxyanthraquinine—sulphonic acid."

A simple statement that aluminium is used to a considerable extent in modern dye-works plant, and even.

it seems, to a certain extent in the dyes themselves, is adequate and more to the point.

ALUMINO-THERMICS.—Aluminium has a powerful affinity for oxygen and this property, as seen in previous chapters, may be an advantage or the reverse. In the interesting series of applications which may be grouped under the above heading, the *raison d'être* of each process to be described hangs on just this peculiar property which is so much maligned in such cases as casting, soldering, etc. The employment of aluminium in the world of steel refining is not new, but it is only of recent years that the matter has been the object of scientific research. The results have demonstrated that the introduction of this metal into molten steel in suitable proportions produces a higher quality steel, and a decrease in the degree of " cropping " and of " wasters" in the ingots.

Aluminium alloys readily with iron in any proportion, but a more important point is its ability to combine immediately with the oxygen in the oxides of iron and other substances with which it is brought in contact. The reaction of such a combination is accompanied by a considerable generation of heat, sufficient to raise the temperature of the whole melt. From the point of view of the steel maker, this latter is a useful feature, chiefly because it enables him to keep the melt in the ladle for a long time by the occasional addition of small percentages of aluminium. If a greater heat be required a little smithy scale may be introduced with the aluminium—a principle which, as will be seen later, has been put to many commercial uses.

For deoxidising purposes only, aluminium must be added in just sufficient quantity to combine with the oxygen in the melt: it is thus entirely used up, and being converted into aluminium oxide, or alumina, rises to the surface in the form of slag. Up to 3 per cent. aluminium has no influence either way on the mechanical properties of the steel, while as little as 0·01 per cent. or 3½ oz. to the ton, is sufficient to " kill " the melt, so that the process is not hampered by narrow limits of handling. The best proportions for ordinary grades of steel range from 1 to 1½ oz. of aluminium per ton, while soft steels require 2–4 oz., these percentages tending to minimise segregation and to give a more rapid solidification of the metal. Experiments on steel so treated show that the ingots on the whole have larger "pipes," but contain denser metal around the pipes; there is a more even distribution of material and less segregation or concentration of carbon, phosphates, and sulphur in the interior and upper parts. Aluminium is generally supplied for this purpose in a granulated form to assist in the distribution of the correct proportions.

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FIG. 29

WELDING WITH THERMIT

It was mentioned above that if a larger generation of heat were required, a little smithy scale added to the melt with the aluminium would bring about the required result. This principle has been developed in an ingenious manner in the patents of Professor H. Goldschmidt, whose welding and metallurgical processes are controlled by Messrs. Thermit, Ltd. Experiments to apply the reducing qualities of aluminium may be traced back some fifty years, but the experimenters one and all attempted the reaction by the application of external heat. There were two outstanding consequences of this method of approaching the problem, firstly the resulting reaction was of so violent a nature that experiments were necessarily confined to small quantities of material, and, secondly, in concentrating on this mode of procedure, the experimenters missed the vital principle that aluminium, mixed with an oxide and suitably ignited, was in itself a potential source of heat in a convenient and usable form.

The compound thermit, then, consists of a mixture of finely granulated aluminium with iron oxide. When ignited in one spot by, for instance, a burning magnesium ribbon, the combustion so started continues throughout the whole mass, accompanied by a rise in temperature up to about 5,400° Fah. The mass is reduced to a molten condition, and separates out into two layers of equal weight; the upper layer, consisting now of aluminium oxide or corundum, occupies about two-thirds of the space, while the remaining third is occupied by pure molten iron. In practice the reaction takes place in a conical crucible lined with refractory material, and provided with a tapping hole at its lower extremity: it forms a convenient and compact source of heat, and its portability has opened up a wide field of utility. Concrete examples of its application which have been exploited to the present date may be summed up under the headings of welding and the production of pure metals from their oxides. A significant proportion of the tram rails of this country and on the Continent are welded by this process, which thus appears capable of competing with the convenient electric welding equipments on their own ground.

In the welding of rails, or repairing of large fractures in mill and marine machinery, the procedure follows simple lines: a mould is placed about the parts to be welded and the molten metal is run through the mould until the parts fuse together, forming a permanent mechanical joint and, in the case of tram-rails, securing good electrical continuity without the necessity for "bonds." The method has been applied with success even to marine propellor shafts and to large toothed wheels, as seen in the accompanying illustrations.

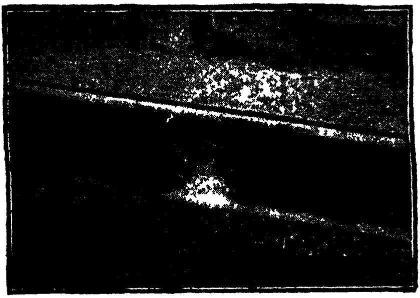

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FIG. 30

COMPLETED JOINT

The metallurgical applications of the process are found chiefly in the production of metals from their oxides, free from carbon and of high purity, the method employed following the lines indicated above in the case of iron.

Among the more important metals produced are chromium, used in the manufacture of chrome-nickel steel and chrome steels generally, including the better grades of high-speed tool steel; manganese, for manganese steel, manganese bronze, etc., and molybdenum, a commercial substitute for tungsten, in the manufacture of special tool steels. Cobalt is also produced in this manner, a metal that enters largely into the production of stainless steel cutlery. All these metals may be produced by this method, using pure materials, at a level of purity of 98–99 per cent., and it is stated that it is difficult to realize this level in the case of these metals by any other means. In addition a wide range of alloys of peculiar value to the metallurgist, ferro-titanium, ferro-copper, ferro-boron, manganese-copper, silicon-copper, etc., are placed by this process at the

FIG. 31

REPAIR BEFORE MACHINING

FIG. 32

FINISHED REPAIR

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disposal of commerce in a form claimed to be essentially free from carbon and other impurities.

We have considered the industrial aspect of the reducing properties of aluminium so far from two points of view. In the first case the reaction is definite, but limited in extent, and in the second the reaction is more violent, and the rise of temperature is very considerable, but the process is still within the limits of control. Thermit is by no means an explosive, and may be thrown on the fire with impunity. But suppose we now consider a case where the reaction is instantaneous, it will be clear that the local rise in temperature will be excessive, and that any gases liberated by the reaction will at once expand to many times their original volume. In other words, we should get an explosion.

A few figures will serve to emphasise the surprising outburst of chemical energy with which aluminium may unite with oxygen. The heat produced by the combustion of one gram-atom of hydrogen is 34,000 units, that of carbon when completely oxidised to carbonic acid gas 97,000, while aluminium evolves no less than 181,000 units. This stupendous reservoir of heat is harnessed to good effect in the explosive known as ammonal, a mixture of aluminium powder with ammonium nitrate. The latter is a white powder resembling common salt in appearance, much used in the production of nitrous oxide, or " laughing gas." It may be handled or hammered or ignited like ordinary table salt and with no more effect, but like most nitrates it may be made to explode when fired by a detonator, and when thus fired it has an advantage over most explosives in that its products of combustion are smokeless and entirely innocuous. Its disadvantage is simply that its explosion is not remarkably powerful. The addition of powdered aluminium, however, remedies this latter effect in a signal manner. The aluminium in its finely divided state, at the first shock and heat of the detonator, seizes upon the oxygen in the nitrate. The intense heat liberated in that reaction expands the gaseous products of combustion in an instant, resulting in the powerful rending effect we associate with an explosion.

Ammonal is notoriously safe to handle. It cannot be made to explode on concussion, and when thrown on the fire it will burn harmlessly away. Its after-products are simply nitrogen, alumina, and water in the form of steam, so that it is a useful blasting agent in mines and confined spaces where the resulting fumes might affect the health of workers. By varying the proportions of the ingredients, gradations of strength may be obtained varying from the most powerful of the nitroglycerine blasting agents down to the mildest black powder, giving the local shattering effect required for splitting up hard quartz rocks, or the slow heave desirable in mining coal and slate. The explosive is not suitable for a propellant: its reaction is too sudden and the disruptive effect too violent. But these qualities recommend it to the exclusion of most others as a bursting charge in shells, and the bombs of aircraft; it was very extensively used in this connection by all the belligerents during the war, and also, it is understood, was largely responsible for the historic blowing up of the Vimy Ridge.

TABLE VI

PHYSICAL, ELECTRICAL, AND MECHANICAL PROPERTIES OF PURE ALUMINIUM

Property.	*Aluminium.*	*Copper.*
Chemical Symbol	Al	Cu
Atomic Weight	26	63·2
Atomic Volume	10·6	7·2
Position in Electro-Chemical Series	10	24
Melting Point, °C.	655	1,100
Specific Heat (water = 1)	0·212	0·094
Thermal Conductivity (Silver = 100)	31·3	73·6
Electric Conductivity (Silver = 100)	59·5	97·5
Co-efficient of Linear Expansion per °C.	0·0000245	0·0000170
Specific Gravity, Cast	2·68	8·78
Specific Gravity, Rolled or Drawn	2·71	8·89
Tensile Strength in Kgs. per sq. mm (Cast)	8–10	15–20
Tensile Strength in Kgs. per sq. mm (Drawn)	15–22	30–40
Tensile Strength in Kgs. per sq. mm (Rolled)	18–23	35–40
Ratio of Tensile Strength to Weight (Equal Sectional Area)	1·63	1·0
Ratio of Tensile Strength to Weight (Equal Electric Conductance)	2·73	1·0
Elastic Limit as % of Tensile Strength	70%	75%
Modulus of Elasticity in Kgs. per sq. mm.	6,890	11,200
Specific Resistance in Microhms at 0°C. Soft	2·700	1·587
Specific Resistance in Microhms at 0°C. Hard	2·801	1·620
Ohms per sq. mm. per metre at 0°C. (Hard Drawn)	·02801	·0162
Co-efficient of increase of Resistance per °C. rise	0·0032–0·0040	0·0043
Weight per kilometre by 1 sq. cm. section, in kgs.	2·71	8·89
Ratio of Conductivities for Equal Area Soft	0·61	1·0
Ratio of Conductivities for Equal Area Hard	0·60	1·0
Ratio of Conductivities for Equal Resistance Soft	0·64	1·0
Ratio of Conductivities for Equal Resistance Hard	0·66	1·0
Ratio of Diameters for Equal Resistance	1·29	1·0
Ratio of Weights for Equal Area	1·0	3·3
Ratio of Weights for Equal Resistance	1·0	2·0

CHAPTER IX

ELECTRICAL

ONE of the most interesting fields in which the use of aluminium is growing from day to day is that of electrical engineering. Its invasion of this territory was at first slow for many reasons, some of which are not hard to trace. To begin with, the metal available for this purpose in the early days was not remarkable either for its purity or for its consistency, and in addition it must be remembered that the whole electrical industry had been built up, so to speak, on a basis of copper. It mattered not what problem turned up in machinery or distribution, all the tables and factors and formulae involved were founded on copper as a standard—the electrical student or engineer "thought" in copper, much in the same way as the automobile industry, to a lesser extent, thinks in terms of petrol at the present day. A man might conceivably discover a substitute for petrol as efficient as this commodity in every way, but should he set out to popularise it on commercial lines, it is possible that he would be required to face not only active criticism from existing interests, but also the far more discouraging passive resistance of a conservative public. One factor alone would make his paths straight: if he could demonstrate that his substitute gave a material economy over the more widely understood fuel, his task would be comparatively light. The fuel might entail minor alterations in carburation; these would be studied with sympathy and overcome: it might possess certain technical advantages over petrol—these would be discovered and discussed in the technical and lay press. Our friend's main efforts would soon be concentrated chiefly on the supply of the commodity in sufficient quantities—the public would do the talking.

The analogy may not be pushed too far, but this, it seems to the author, broadly indicates the history of aluminium electrical work. For while probably few keener controversies have been waged around and about any new departure in engineering, it is impossible not to observe that the use of the metal has been steadily extending, until at the present time there are some 18,000–19,000 tons (equivalent, as will be seen, to double this quantity in copper) employed on overhead transmission alone, extensive areas are fed by aluminium insulated cables, and the use of the light metal in station bus-bars and in the field coils of heavy traction motors, is becoming almost standard practice. The grounds of controversy, though interesting, fall outside the legitimate scope of this book; the chief point that concerns us is, that since continental designers are at present re-calculating their tables and standards to suit aluminium conditions, it is probably worth our while to examine wherein these conditions diverge from current copper practice.

To commence with, how does the conductivity of aluminium compare with that of copper? The minimum conductivity of the hard drawn wire supplied for electrical purposes is 60 per cent. of the International standard for annealed copper. On this basis an aluminium conductor of the same length and resistance as one of copper will have a cross sectional area in the ratio of 100 to 60, or 1·66 to 1.

The specific gravity of aluminium wire is 2·71, while that of copper is 8·89, and so for a given volume copper is 3·3 times as heavy as aluminium, while for a given resistance, *which is the figure we want, the weight ratio* will be copper 3·3, aluminium 1·66, or approximately 2 to 1. The significance of this is that 1 lb. of aluminium will do the work of 2 lb. of copper, and that it must show a saving, therefore, at anything under double the price of the red metal.

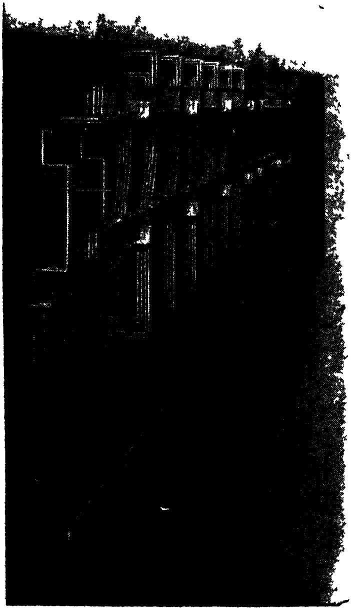


FIG. 33

A LARGE ALUMINIUM INSTALLATION ERECTED BY THE BRITISH WESTINGHOUSE ELECTRIC AND MANUFACTURING CO., LTD.

This point established, we may proceed to consider the branches of electrical engineering in which aluminium has proved a competitive material. Beginning from the point of generation, it may be mentioned that the Germans wound a number of their dynamos, convertors, transformers, etc., during the war with aluminium. Primarily a war measure consequent on the scarcity of copper, this step apparently proved satisfactory, and in view of the economy obtained some of the larger firms are making their preparations for winding electrical machinery with aluminium as a commercial proposition. In the bus-bars and connections we are on firmer

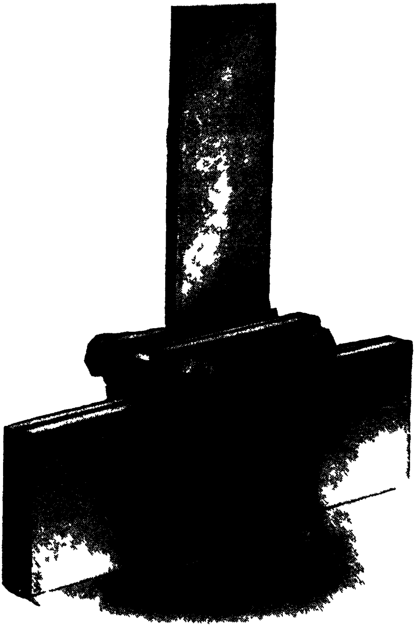


FIG. 34

METHOD OF CLAMPING A T-JOINT WITHOUT DRILLING HOLES IN THE BARS ground, because the metal has long demonstrated its merits in this territory, and has become a familiar sight in the larger generating and substations. For such installations the size of the conductor is determined not so much by voltage drop as by rise in temperature, and here the increased section of aluminium shows to advantage because of the greater area of radiation afforded. So that an increase of 35–40 per cent. only, over a given section in copper, will place the metals on a par from the point of view of temperature rise, and is used in place of the 50 per cent. increase necessary for equal resistance. A rise of 30° C. is allowable by United States law, and 25° C. on the Continent, while our own conservative country is content with a modest and unnecessarily safe 20° C. Where it is desired to run the bus-bars at temperatures other than 20° C. rise, the current I_1, to give a rise of T° C., is given by the formula

$$I_1 = I\sqrt{T/20},$$

where I is the current giving 20° C. rise.

When dealing with heavy currents it is usual practice with both metals to use laminated bus-bars, and in the case of aluminium these are spaced by distance pieces of the same metal between individual bars. The arrangement gives a better radiation than a single bar of equivalent conductivity, but unless the laminae are spaced a minimum of ⅝ in. apart, free radiation from each is interfered with, and allowance should be made for this in the aggregate section. To make this clear a single bar 4 in. × ¼ in. will carry a current of 695 amperes with a temperature rise of 20° C. Three such bars should logically carry 2,085 amperes, but if spaced only ¼ in. apart they will in practice carry only 1,670 amperes with the same rise in temperature.

In jointing rectangular bars of aluminium they should be rough filed at the points of contact, the direction of filing on the two bars to be jointed being at right angles to one another, this practice ensuring a thorough bedding of the surfaces when bolted together. If space permits, they should then be clamped together on the lines indicated in Fig. 34, but in the event of there being insufficient room for clamps, they may be overlapped, drilled, and bolted up; the contact area being more liberally apportioned in this case to allow for the space occupied by bolts. The minimum contact area for a simple overlap joint should be ten times the cross-section of the bar: where the bars are butted together and a fish-plate used, the area of the latter should not be under forty times that of the bar, and where two fish-plates are used, their individual area should be twenty times the cross-section. These are the minimum areas for satisfactory passage of the current: but in point of fact in practice a larger overlap is demanded in any case by mechanical considerations. A 4 in. × ¼ in. bar would, by the above, require 10 sq. in. contact area or an

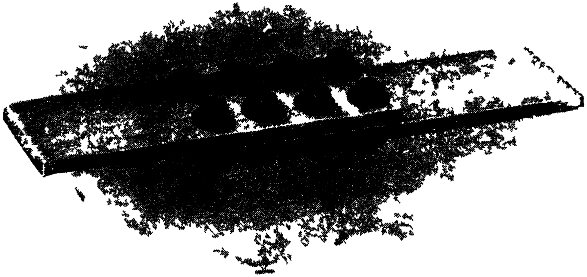


FIG. 35

JOINT IN FLAT BAR, SHOWING A SIMPLE OVERLAP

overlap of 2½ in. This gives very little room for the necessary bolts and in practice this overlap is at least doubled.

Clamps are preferable on the whole, particularly in heavy furnace connections, and when they are used both they and their bolts should be of non-magnetic material, and where they are liable to come into contact with chemical fumes or damp, it is advisable to insulate them from the bars by thin sheets of mica or presspahn, and to paint the whole joint with a waterproof compound.

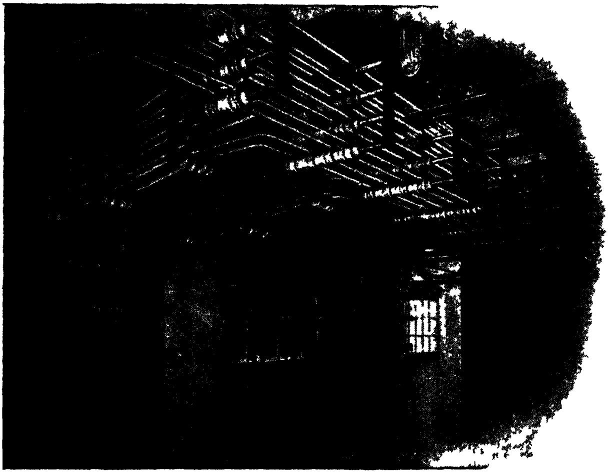


FIG. 36

ALUMINIUM ROUND ROD CONNECTIONS INSTALLED BY THE B.T.-H. CO., LTD.

For long lengths of feeder and battery connections, solid round rod is most suitable. It is very easily worked

TABLE VII

ALUMINIUM ROUND RODS

Diameter.		*Area.*		*Weight.*		*Amperes* to give 20°C Rise
In.	M/m.	Sq. In.	Sq. M/m	Lb./ft.	Kg./M.	
2	50·8	3·14	2030	3·69	5·49	1625
$1\frac{15}{16}$	49·2	2·95	1900	3·46	5·15	1550
$1\frac{7}{8}$	47·6	2·76	1780	3·24	4·83	1480
$1\frac{13}{16}$	46·0	2·58	1660	3·03	4·51	1405
$1\frac{3}{4}$	44·4	2·40	1550	2·83	4·21	1335
$1\frac{11}{16}$	42·9	2·24	1440	2·63	3·91	1265
$1\frac{5}{8}$	41·3	2·07	1340	2·44	3·63	1195
$1\frac{9}{16}$	39·7	1·92	1240	2·25	3·35	1130
$1\frac{1}{2}$	38·1	1·77	1140	2·08	3·09	1060
$1\frac{7}{16}$	36·5	1·62	1050	1·91	2·84	995
$1\frac{3}{8}$	35·0	1·48	955	1·74	2·59	930
$1\frac{5}{16}$	33·3	1·35	873	1·59	2·37	868
$1\frac{1}{4}$	31·7	1·23	792	1·44	2·15	807
$1\frac{3}{16}$	30·2	1·11	714	1·30	1·94	745
$1\frac{1}{8}$	28·6	0·994	641	1·17	1·74	686
$1\frac{1}{16}$	27·0	0·887	572	1·04	1·55	630
1	25·4	0·785	507	0·923	1·37	575
$\frac{15}{16}$	23·8	0·690	445	0·811	1·21	521
$\frac{7}{8}$	22·2	0·601	388	0·706	1·05	470
$\frac{13}{16}$	20·6	0·518	334	0·609	0·907	421
$\frac{3}{4}$	19·0	0·442	285	0·519	0·772	373
$\frac{11}{16}$	17·5	0·371	239	0·436	0·650	327
$\frac{5}{8}$	15·9	0·307	198	0·360	0·536	285
$\frac{9}{16}$	14·3	0·248	160	0·291	0·433	243
$\frac{1}{2}$	12·7	0·196	127	0·231	0·343	204
$\frac{7}{16}$	11·1	0·150	96·8	0·176	0·262	168
$\frac{3}{8}$	9·52	0·110	71·3	0·130	0·193	133
$\frac{5}{16}$	7·94	0·0767	49·5	0·0901	0·134	101
$\frac{1}{4}$	6·34	0·0491	31·7	0·0577	0·0858	72
$\frac{3}{16}$	4·76	0·0276	17·8	0·0324	0·0482	41

in any direction and jointed, and it may be supported neatly on racks along the walls and in trenches, etc. Here again, for heavy current work several rods in parallel give better results than a large single one: a single rod of 2 in. diameter, for instance, carrying 1,630 amperes, while four 1 in. diameter rods giving the same total sectional area will carry 2,300 amperes with the same rise in temperature. In working with round rod of large section, the flame of an ordinary blow-lamp applied to the part to be bent will facilitate the work. If the heat is applied until the rod is just hot enough to bend easily the bend may be finished without further heating, except in the case of unusually large sections. A rod of 1½ in. diameter may readily be given a right-angled bend with a mean radius not exceeding 3 in. Small sizes of ½ in. diameter and under may be bent cold. The bends shown in Fig. 38 were carried out in 1¼ in. diameter rod, and are characteristic of the complicated work which may be carried out in this metal.

The jointing of rods is best done by butt-welding, which gives a true homogenous joint with a conductivity equal to the remainder of the rod. Wire and small rods up to ¼ in. diameter may be welded by hand by holding the two ends in the flame of an ordinary blow lamp until the metal begins to flow, when they are firmly pressed together. The film of oxide is squeezed out together with the surplus metal, forming a collar around the joint, and the two rods flow together without chemical hindrance. Larger diameter rods require some sort of backing to concentrate the heat on the ends to be welded, and this may be combined with a mechanical guide or rest, and some simple device as shown in Fig. 37 for affording an additional leverage. It is important to avoid lateral movement, and until the

Fig. 37

SIMPLE APPARATUS FOR THE WELDING OF LARGE SIZES OF ALUMINIUM ROUND ROD, SHOWING ARRANGEMENTS FOR APPLYING THE NECESSARY END PRESSURE.

metal has set the rods must be kept quite stationary. The surfaces to be welded should be about ⅛ in. apart, and should be kept in the reducing part of the flame until the metal begins to melt and show signs of dropping. They should then be pressed slowly and firmly together until sufficient metal has been forced out to form an irregular collar about twice the diameter of the rod. The flame is then removed, but pressure is maintained until the joint has set. A slight twisting movement when first applying pressure is useful in assisting in the removal of the oxide film, and the result will be a perfect joint, which when filed up and polished is difficult to detect from the rest of the rod.

FIG. 38

COMPLICATED BENDS IN ALUMINIUM ROUND ROD

In the case of very large rods, or those in inaccessible positions or otherwise unsuited to butt-welding, a screwed coupling may be used, preferably designed with right and left-handed threads like a railway coupling. Terminals can be readily forged on the ends of aluminium rod, being worked up either hot or cold. When cold forged the terminal might be annealed with advantage before hammering, and the same remark with regard to riveting may be applied here also: many light blows give better results than a few heavy ones.

Overhead Transmission.—The design of the long-distance transmission line presents problems which fall outside the range of this book, and it would be superfluous to do more than generalise on such points wherein the use of aluminium would modify any accepted design in copper.

TABLE VIII

SAFE CURRENTS FOR BARE STRANDED OVERHEAD ALUMINIUM CONDUCTORS

Size.	Effective Section. sq. inches	50° F. Rise.	100°F Rise.	Size.	Effective Section. sq.inches	50°F. Rise.	100°F Rise.
3/16	0·009458	26	26	19/8	0·3748	412	558
3/14	0·01478	35	36	19/7	0·4534	466	640
3/12	0·02490	50	54	19/6	0·5396	536	725
3/10	0·03783	75	95	19/5	0·6579	612	835
3/8	0·05911	94	132	37/9	0·5909	571	772
7/12	0·05845	92	129	37/8	0·7295	663	908
7/11	0·07270	117	158	37/7	0·8826	770	1048
7/10	0·08853	143	195	37/6	1·0510	875	1193
7/9	0·11210	156	220	37/5	1·2800	1013	1390
7/8	0·13800	191	271	61/8	1·2020	967	1320
7/7	0·16740	206	298	61/7	1·4550	1107	1525
7/6	0·19920	248	350	61/6	1·7310	1263	1743
7/5	0·24290	290	412	61/5	2·1110	1468	2010
19/10	0·23980	288	410	91/6	2·5830	1718	2313
19/9	0·30360	341	481	91/5	3·1480	2001	2720

The history of the use of aluminium, in place of a metal which for long years had been accepted as the only suitable material for transmission of electrical energy, commences in or about the year 1898 with a small single pole line from Snoqualmie to Seattle, a distance of 32 miles. It was a modest beginning, but an innovation which apparently met with success, for the intervening twenty years, so marked by advances in design of line and equipment, have seen a no less striking enterprise in the development of the light metal as an economical substitute for copper. In 1898 there were about 32 miles of aluminium line in use; in 1918 there can hardly have been less than 6,000 miles of either simple aluminium strand or aluminium steel-cored cable in operation, and counting branch lines and distribution this figure is probably on the conservative side. During these twenty years corresponding advances have taken place in the production of metal of increasing purity, and in the art of drawing the wire at such speeds and reductions as will give the most efficient combination of conductance and tenacity, so that there is little reason to suppose that the striking increase in the use of this metal during the past decade will show any tendency to fall off in the future. As long, indeed, as aluminium can show its present economy its employment must tend to extend rather than diminish: the keynote to its success is economy, attained in this case not merely from a comparison of first cost with copper, but also from certain considerations of a technical nature which are indicated in the following.

Transmission and distribution systems are widening their scope rapidly at the present time, and as the areas supplied from one central source grow in extent, so does the large standing charge of capital laid out in cable and line assume more significant proportions. The energies of electrical engineers are, therefore, concentrated on the reduction, as long as this is consistent with reliability, of what must be looked upon as so much capital lying idle. The simplest method of cutting down line material consists in raising the voltage.

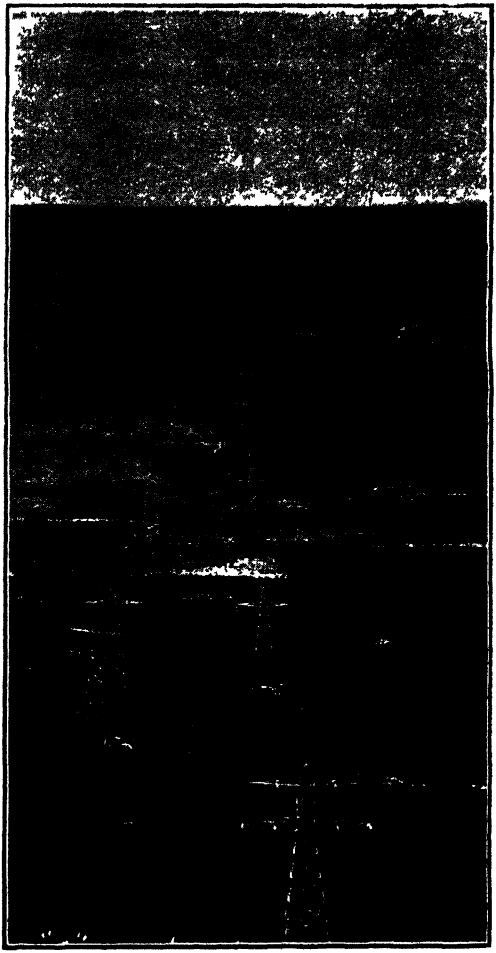


Fig. 39

THE 110,000 VOLT LINE OF THE ONTARIO HYDRO-ELECTRIC COMMISSION, EMPLOYING ALUMINIUM STRAND

Originally a useful working rule was to allow a thousand volts for every mile the power was to be transmitted, a rule which worked very well until modern schemes began to transmit power over distances which a comparatively short time ago would have been considered impracticable. Power is now sent in bulk over 400 miles at a stretch, while the maximum operating pressure so far found to give satisfactory working is about 165,000 volts, and this only in warm, dry climates.

There is one serious limiting factor in the use of these extra high tensions: the upper limit of voltage is reached when the tension is sufficient to break down the resistance of the surrounding atmosphere, and energy leaks off in the form of " corona." The loss of power due to this phenomenon may be calculated with the simplicity and accuracy of any other problem in high-tension alternating work, and in some cases it has been known to exceed 60 kw. per mile. It will therefore be seen that with indiscriminate raising of the voltage a point is soon reached at which a further increase is no longer an economical proposition. The extent to which this loss occurs is, apart from the question of voltage, determined by many factors, pre-eminent among which are (*a*) the size of the conductors, and (*b*) the spacing between them. The smaller the wires and the closer they are together, the lower will be the critical voltage at which corona commences (see Table IX) and if this critical voltage is lower than that at which the line is operating, losses of power must occur. Any method of increasing the size of the conductor, therefore, will modify these losses, and to this end the practice has grown up of stranding copper conductors about a core of hemp or other material. The same effect, however, is automatically obtained by the use of simple aluminium stranded conductors, which give a diameter some

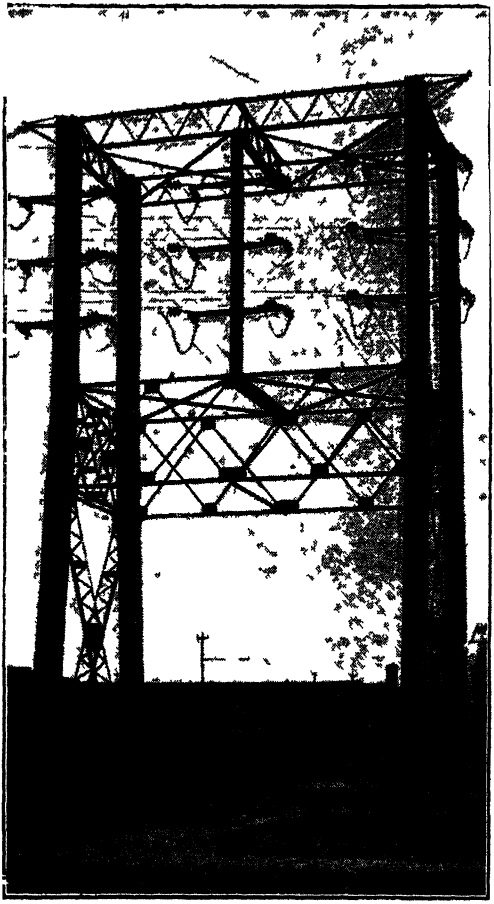


FIG 40

SPECIAL ARCHBOLD-BRADY ANCHOR STRUCTURE ON THE NIAGARA FALLS-BUFFALO 22,000-VOLT TRANSMISSION LINES CARRYING FOUR CIRCUITS IN ALUMINIUM AND TWO IN COPPER

TABLE IX

CORONA VOLTAGES ON OVERHEAD CONDUCTORS

The following figures are calculated on F. W. Peek's formula (see *A.I.E.E. Trans.* 1911, p. 1485) and show the pressure at which corona discharge begins to take place under the most unfavourable weather conditions.

Cond. Spacing	Copper Cond. 40 Sq. Mm. Section	Equiv. Alum. Cond	Copper Cond. 50 Sq. Mm. Section	Equiv. Alum. Cond.	Copper Cond. 60 Sq. Mm. Section	Equiv. Alum. Cond.	Copper Cond. 70 Sq. Mm. Section	Equiv. Alum. Cond.	Copper Cond. 80 Sq. Mm. Section	Equiv. Alum. Cond.	Copper Cond. 90 Sq. Mm. Section	Equiv. Alum. Cond.	Copper Cond. 100 Sq. Mm. Section	Equiv. Alum. Cond.	Copper Cond. 125 Sq. Mm. Section	Equiv. Alum. Cond.
Cms.	Kilovolts		Kilovolts		Kilovolts		Kilovolts		Kilovolts		Kilovolts		Kilovolts		Kilovolts	
200	77	100	85	109	92	117	99	125	105	132	111	138	116	143	130	159
250	79	101	88	112	95	121	102	129	108	136	114	143	120	148	134	164
300	81	103	90	115	97	125	105	133	111	140	117	147	123	152	138	168
350	83	105	92	118	100	128	107	137	114	144	121	151	127	156	142	172
400	84	106	94	120	102	131	110	140	117	148	124	155	130	160	146	176
450	86	108	96	122	104	134	112	143	119	151	126	158	133	164	149	180
500	87	109	98	125	107	137	114	146	122	154	128	162	136	167	152	184

For any given amount of power transmitted and for any given voltage drop, the corona loss will be lower with aluminium than with copper in accordance with the ratio of diameters.

26–28 per cent. in excess of their equivalent in copper, and in addition provide a material saving in first cost. The use of aluminium often entirely eliminates corona loss, and always affords a higher critical voltage at which this phenomenon occurs.

FIG. 41

ALUMINIUM CHOKE COILS

With regard to the spacing between conductors, mechanical reasons necessitate the spacing of aluminium cables rather wider apart than those of copper. The lower tensile strength often means a greater sag between poles, and a consequent greater liability in the wires to swing together, and they are therefore so spaced as to minimise this danger. This means longer arms to the towers, but not necessarily heavier towers because the light weight and low end pull of an aluminium line tends to lighter construction generally, and largely neutralises the increased cost of towers due to wider spacing. Similarly, this wider spacing has been criticised from the point of view of line regulation, but this again is neutralised by the bigger diameter of the aluminium cable. The wider spacing, which, unless the cable has a steel core, is mechanically necessary, has at least one useful feature in its reduction of losses due to corona. For long spans the steel-cored aluminium cable is becoming deservedly popular: not only is a saving effected on the cost of the conductor, but in this case the tower-line is also cheaper than a corresponding line designed to be strung with copper, and the material gives so satisfactory a factor of safety that this lower cost in the towers shows tendencies towards further reduction, owing to the use of lighter towers than would otherwise have been considered safe.

With regard to erection, much the same practice is followed with both metals: they are now invariably made up as stranded cables, and as touching the question of damage during erection they are much on a par, with one notable exception. Aluminium is but half the weight of copper; it therefore needs less hauling about, and its flexibility and general handiness, particularly in the larger sizes of cable, generally mean speedier progress in erection. It is hardly necessary to point out that dragging either metal over the ground is a practice to be discouraged, however apparently smooth and free of stones the neighbourhood may be: the better method is the one usually adopted in running long lines in the States, where the cables are passed over large, easy running snatch-blocks slung from each tower arm.

JOINTING.—Aluminium strand lends itself to several types of joint of proved merit, the two most widely employed being the torsion and the compression joints. In the former case the two ends of the cable are laid side by side in an oval sleeve of from 20 to 36 in. in length, according to the section of the cable. A double handled

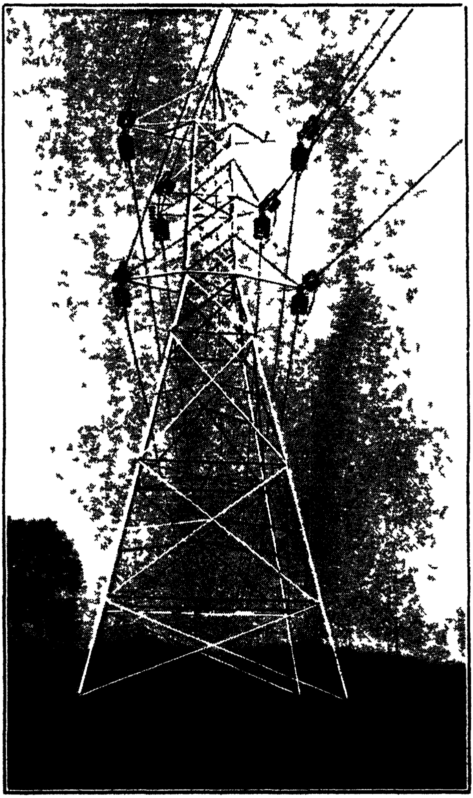


FIG 42

HEAVY ANCHOR TOWER CONSTRUCTION WITH ALUMINIUM STEEL-CABLES AND LOCKE STRAIN INSULATORS ON THE CEDAR RAPIDS LINE clamp is then bolted over each end of the sleeve, and these two clamps are turned in opposite directions, giving about three complete twists to the sleeve and forming a splice as shown in Fig. 43. The soft sleeve becomes hardened in the process and is forced into the interstices of the strand; the resulting joint is highly efficient from an electrical point of view, and mechanically will take a greater stress than the remainder of the line without failure.

Fig 43

TORSION SLEEVE JOINT ON ALUMINIUM STRAND

For cables of upward of $\frac{3}{4}$ in. diameter the torsion joint involves rather heavy labour, and the compression joint is more widely used. The cable ends are butted together within a cast aluminium sleeve, which is hydraulically squeezed at intervals in its length by means of a small portable 100-ton press. The slow squeeze causes the metal to flow into a solid block at the points of pressure, forming what amounts to a cold weld with the imprisoned strand, and resulting in an excellent permanent joint.

The use of aluminium in overhead transmission is naturally most extensive in those countries where the development of natural power resources is unhampered by short-sighted legislation, and difficulties in obtaining way-leaves, etc. The longest transmission line in the world, Bishop's Creek, California, 404 miles, and the second longest, Big Creek to Los Angeles, 241 miles, are both entirely of aluminium; while the third longest, that transmitting power from the Niagara Falls to Windsor, a distance of 229 miles, has aluminium cables for half the distance, forming a useful comparison in working. The first-named is interesting in that, although one of the most extensive power distribution schemes in existence, it is one of the very few large networks having no large town in the system, the power being utilised in mining and irrigation. The line is the property of the Southern Sierras Power Co., and from the power station at Bishop's Creek in the Sierra Nevada the lines convey energy at 140,000 volts to a substation at San Bernardino, 238 miles away. Thence a 55,000 volt pole line conveys the current 166 miles to El Centro via Imperial Valley. The first section is strung with aluminium steel-core cable of ·184 sq. in. sectional area, with an aluminium-steel ratio of 6, while the second consists of simple aluminium strand of ·132 sq. in. area. The second power scheme referred to above is that of the Pacific Light and Power Corporation, the main line of which supplies the city of Los Angeles with energy generated at Big Creek 241 miles away. The details of this scheme are worked out on heroic lines. The huge head of 4,000 ft. is utilised in two stages by turbines of 20,000 horse-power, while the operating voltage is 150,000, the highest yet adopted on a commercial scale.

There are many large power schemes in the States and in Canada employing aluminium conductors, the Pennsylvania Water and Power Co., the Shawinigan

Water and Power Co., and numerous other concerns of a like nature transmit their power wholly or in part by the medium of this light metal.

In Europe one of the most remarkable power plants is that of the Rjukan Company in Norway; the distance transmitted in this case is only three miles, but twenty circuits of ·471 sq. in. aluminium cables are used to take the huge power of 170,000 KVA. at 20,000 volts to the factory, where it is used mainly in the fixation of atmospheric nitrogen. An interesting point about this scheme is that the metal has proved to be unaffected by the nitric acid and nitrous fumes emanating from the factory.

FIG 44

MAKING A COMPRESSION JOINT ON ALUMINIUM-STEEL CABLES: SOUTHERN SIERRAS POWER CO.

Other power schemes which occur to one, out of over a hundred employing this metal, are the Uddeholms Aktiebolag in South Sweden, the Lake Coleridge to Christchurch system run by the New Zealand Government, and one in this country constructed in the Aldershot district for the War Office, all of which, like the above-mentioned examples, use aluminium cables in constant operation without any trouble beyond that which is normally associated with the transmission of power at high voltages over long distances.

INSULATED CABLES.—From the transmission to the distribution, and the field of insulated cable work. Aluminium has not made such sweeping inroads into this branch as seen in overhead transmission, partly because the insulation and protection of its larger core rather modifies the otherwise substantial saving it offers, but chiefly because there was little experience available at first with regard to its jointing, and undoubtedly trouble was experienced in this direction. Aluminium cables may not be sweated together with the ease associated with copper, nor with the certainty of reliable service afterwards, and the only methods likely to give the high level of reliability required in electrical work are either some form of mechanical clamp or a tedious process of butt-welding each strand.

In spite, however, of the increased cost of insulating and armouring, the net economy of aluminium was still of a nature to encourage research in the direction of a good joint, and that these efforts have met with a measure of success is indicated in the considerable mileage of aluminium insulated cable in operation on the Continent and in this country. There are three chief classes of cable in common use, the paper-insulated lead-sheathed, the bitumen insulated, and the rubber-insulated cable. The first class is the nost commonly used, and in this class the core forms a large percentage

TABLE X

BARE ALUMINIUM STRANDED CABLE

Nominal Sectional Area		No. of Wires	Diameter of each Wire		Diameter of Cable	
Sq. mm.	Sq. in.		Mm.	In.	Mm.	In.
10	·0155	3	2·06	·081	4·4	·175
20	·0310	7	1·91	·075	5·7	·226
30	·0465	7	2·34	·092	7·0	·276
40	·0620	7	2·70	·106	8·1	·319
50	·0775	7	3·01	·118	9·0	·355
60	·0930	7	3·30	·130	9·9	·390
70	·1085	19	2·16	·085	10·8	·425
80	·1240	19	2·32	·091	11·6	·457
90	·1395	19	2·46	·097	12·3	·484
100	·1550	19	2·59	·102	13·0	·512
120	·1860	19	2·84	·112	14·2	·559
140	·2170	19	3·06	·120	15·3	·602
160	·2480	19	3·28	·129	16·4	·646
180	·2790	37	2·49	·098	17·4	·685
200	·3100	37	2·62	·103	18·3	·720
225	·3488	37	2·78	·109	19·5	·767
250	·3875	37	2·93	·115	20·5	·807
275	·4263	37	3·08	·121	21·6	·850
300	·4650	61	2·50	·098	22·5	·886
325	·5038	61	2·61	·103	23·5	·925
350	·5425	61	2·70	·106	24·3	·957
375	·5813	61	2·80	·110	25·2	·992
400	·6200	61	2·88	·113	25·9	1·02
425	·6588	61	2·98	·116	26·9	1·06
450	·6975	91	2·51	·099	27·6	1·09
475	·7363	91	2·58	·102	28·4	1·12
500	·7750	91	2·65	·104	29·2	1·15

TABLE X—*Continued.*

BARE ALUMINIUM STRANDED CABLE

Resistance at 20° C.		Weight		Equivalent Section of copper	
Ohms p, km.	Ohms per 1,000 yd.	Kgs. per km.	Lb. per 1,000 yd.	Sq. mm.	Sq. in.
2·856	2·64	27·6	55·7	6·1	·00937
1·428	1·32	55·3	111·3	12·1	·0188
0·952	·879	82·9	167	18·2	·0282
·715	·660	110·6	223	24·2	·0375
·572	·527	138·2	278	30·3	·0470
·475	·440	166	334	36·3	·0563
·408	·377	194	390	42·3	·0655
·357	·330	221	446	48·4	·0750
·317	·293	249	501	54·4	·0844
·286	·264	276	557	60·5	·0937
·238	·220	332	669	72·6	·1125
·204	·188	387	780	84·8	·131
·178	·165	442	891	96·7	·150
·159	·146	498	1002	109	·169
·143	·132	553	1113	121	·188
·127	·117	622	1250	136	·211
·114	·106	691	1391	151	·234
·104	·0958	760	1530	166	·258
·0952	·0879	829	1671	182	·282
·0878	·0811	898	1810	197	·305
·0817	·0753	967	1950	212	·329
·0762	·0704	1038	2085	227	·352
·0715	·0659	1106	2225	242	·372
·0672	·0621	1174	2368	257	·398
·0635	·0586	1243	2520	272	·421
·0601	·0555	1312	2642	288	·446
·0572	·0528	1382	2783	303	·470

of the whole cable, which brings out the economic value of aluminium. Table XI gives the thicknesses of dielectric and lead sheathing as specified by the Engineering Standards Committee, but it should be pointed out that these are based largely on mechanical considerations rather than on electrical, and bearing in mind

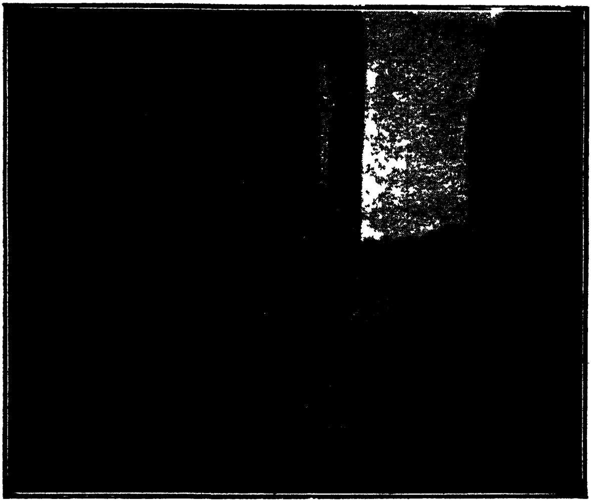


FIG. 45

LAYING ALUMINIUM CABLES FOR THE PARIS GENERAL OMNIBUS CO.

the light weight of aluminium it seems that they might be revised with advantage. The feeder system of the Paris General Omnibus Company uses some 650–700 tons of aluminium, for the most part insulated with paper and sheathed in lead, with an armouring of double steel tape. This instance is of interest because half of this amount was installed as an experiment, the other half being laid down only after proof of satisfactory operation was established, and it is claimed that an economy was obtained of from 8–12 per cent. over copper.

The main point of note for the reader, in regard to both bitumen and rubber insulations, lies in the immunity from corrosion by sulphur and its compounds, which has been referred to previously as characteristic of aluminium, and which here dispenses with the cost of tinning the conductor. In addition, should the temperature of the cable rise unduly through overloading or external causes, either of these insulations will soften, and there is a tendency for the core to decentralise. This possible cause of damage is much modified where aluminium is concerned, by reason of its larger bearing surface and low weight; the mechanical pressure on the dielectric being under two-fifths of that caused by copper.

There is a fair mileage of aluminium insulated cable in this country, laid mostly in the London and Lancashire areas, and a growing amount on the Continent at Lyons, Rennes, Nuremburg, Frankfurt, Zurich, Bitterfeld, etc. The last named has a peculiar interest at the present time (when attention in this country is turning to the possibilities of high-tension transmission by underground cables), because of the unusual operating pressure employed. The cable, which is of stranded aluminium of 100 sq. mm. sectional area, was made for the Prussian States Railways by Messrs. Siemens-Schuckert, and forms part of a 60,000 volt feeder system. The middle point of the system is earthed at the station through a high resistance, so that the actual tension between conductor and earth is limited to 30,000 volts. But even so this operating pressure is of an unusually high order in insulated cable work, and the core bears so small a ratio to the whole cable that it is difficult, at first sight, to conceive how any great economy could be gained by the use of aluminium. The reason for its adoption here has more of a technical nature: in dealing with such tensions the amount of insulation may be *less* with aluminium on account of its larger core. This apparent paradox is explained by the fact that a larger core necessarily gives a lower surface density per unit area of the conductor, and therefore throws a lower stress on the insulation in that area.

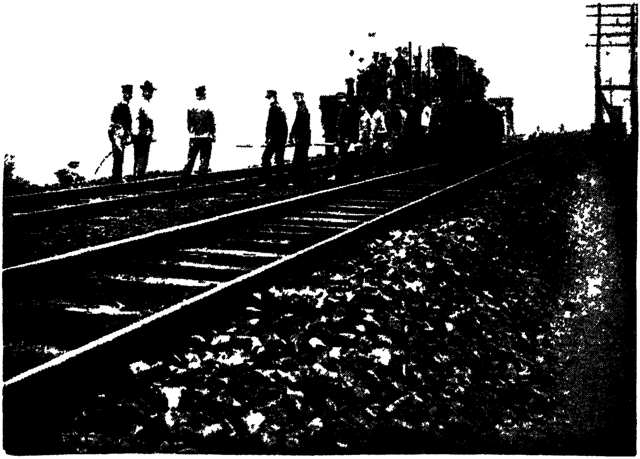


FIG. 46

LAYING THE HIGH-TENSION CABLE ON THE DESSAU-BITTERFELD LINE

In the case under discussion, if a copper conductor of equivalent current carrying capacity had been employed, its section would have been about 57 sq. mm. in place of 100 sq. mm., and a stress would have been thrown on the insulation some 14 per cent. in excess of that given by the lighter metal. To give the copper cable the same factor of safety, the insulation would have been increased to 16·7 mm. radial thickness, making an overall diameter inside the lead sheathing of 42·9 mm. as against the 39 mm. of the aluminium cable. It is clear, therefore, that in these and similar circumstances, there is a useful economy gained, not on the actual conductor alone, but also on the insulation material and on the costly lead sheathing which envelops the whole.

FIG. 47

CONTINENTAL TYPE OF CABLE JOINT

JOINTING.—As before mentioned, soldering is not recommended for jointing aluminium cables, although it has been adopted in a few cases with varying results. A good and reliable joint may be made by cast welding, but the process involves the baring back of the conductor to a considerable distance to avoid injury to the insulation. Experience has shown that the problem is best solved by well designed mechanical connectors, and of these there are now several types available of good electrical efficiency and proved reliability. On the Continent the commonest practice is to employ a bronze sleeve fitted with numbers of grub-screws (Fig. 47), which when screwed home bed firmly into the strand. The arrangement works well enough in practice and is widely employed, but it must be confessed that it falls short of one's ideal of an engineering job, and a clamp which finds more favour in this country is that illustrated in Fig. 48. These connectors are "stepped" in order to distribute an intimate contact throughout all layers of the conductor. The design is compact and mechanically sound, and its electrical efficiency has been thoroughly tested during the past few years in many important installations.

FIG. 48

STEPPED TYPE OF JOINT USED IN ENGLAND

Reports of trouble occur from time to time with aluminium cables, as indeed they do with those of copper, and probably would if they were made of pure silver. It has always been difficult in practice to arrive at any reliable conclusion as to whether a fault developed owing to the use of any particular metal, or to environment, or general conditions of working which might or might not affect either metal to an equal degree. Perhaps the foregoing may at least indicate that the metal

TABLE XI

CURRENT CARRYING CAPACITY OF INSULATED ALUMINIUM CABLES

Cross Sectional Area		INSULATED. Average Values of Standard Ratings			BARE. Current in amps. giving a rise of temperature of		
		Paper-Lead	Vulcanised Bitumen	Vulcanised India-rubber	15° C.	30° C.	60° C.
Sq.mm	Sq. Ins.	Amps.	Amps.	Amps.	Amps	Amps.	Amps.
2000	3·10	1730	1490	1190	1480	2030	2740
1800	2·79	1600	1380	1100	1370	1880	2540
1600	2·48	1470	1260	1010	1250	1730	2330
1400	2·17	1340	1150	925	1140	1570	2110
1200	1·86	1200	1030	828	1010	1400	1880
1000	1·55	1050	903	725	888	1220	1640
900	1·39	977	840	674	819	1130	1520
800	1·24	900	774	621	748	1040	1390
700	1·08	820	705	566	677	940	1260
600	·930	739	633	508	600	830	1120
500	·775	650	559	448	520	721	977
400	·620	557	479	384	439	608	826
300	·465	458	384	316	355	489	664
200	·310	350	301	241	262	360	489
180	·279	324	279	223	242	336	454
160	·248	298	256	206	220	308	418
140	·217	274	235	189	198	280	383
120	·186	243	209	168	175	242	342
100	·155	215	185	148	152	211	300
90	·139	198	170	137	140	195	280
80	·124	181	156	125	129	179	244
70	·108	163	140	112	116	162	220
60	·0930	145	125	100	104	145	196
50	·0775	128	110	88·4	90·0	126	120
45	·0697	118	101	81·4	83·6	117	157
40	·0620	109	93·8	75·3	76·6	107	144
35	·0542	99·4	85·5	68·6	70·0	93·7	131
30	·0465	89·4	75·8	61·7	62·5	87·0	117
25	·0387	79·0	67·9	54·5	55·4	76·0	102
20	·0310	68·1	58·5	47·0	47·1	64·0	87·0
18	·0279	63·6	54·7	43·9	43·9	59·1	80·3
16	·0248	58·9	50·6	40·6	40·0	54·2	73·6
14	·0217	53·8	46·3	37·1	36·7	49·0	66·6
12	·0186	48·5	41·7	33·5	32·6	43·7	59·4
10	·0155	43·0	37·0	29·7	28·3	38·0	51·4
8	·0124	37·0	31·8	25·5	24·0	32·0	42·7
6	·00930	30·0	25·8	20·7	19·0	26·0	34·4
4	·00620	23·0	20·6	15·9	14·0	18·5	25·0

has passed its teething stage in its application to insulated cable work. It is improbable that the material will ever completely supersede the very efficient service rendered by copper in this great field, and it is perhaps not altogether desirable that it should. A certain healthy competition in the key commodity of a great industry has a value which is not to be ignored. But whether or no copper continues to be specified in distribution schemes to the same extent as formerly, would appear to depend now, not so much on any question of the capabilities of aluminium, as on personal preference or the pockets of the promoters.

ALUMINIUM OXIDE INSULATION.—The troubles in jointing met with in the early days all centre on the film of oxide, which invariably forms on the surface of aluminium, and which has a fairly high electrical resistance. That this property in the metal is not entirely to its detriment in electrical work is shown in the following discussion of its possibilities as an actual insulation.

In most branches of the electrical industry the capability of an insulating material to withstand high temperatures is a most desirable, if not an essential, asset. From the earliest days of the industry, therefore, the problem has attracted considerable attention, and as far back as 1883 a patent was granted to Messrs. Chertemps et Cie. of Paris, providing for the insulation of electrical conductors by running them through solutions of various inorganic salts. The water of crystallization was then driven off, and the solid insulating covering remained on the conductor capable of standing with safety temperatures up to a red heat. A notable advance on this fundamental idea was made in 1900 by Dr. Reissig, of Munich, who carried out a series of experiments with clay or aluminium oxide

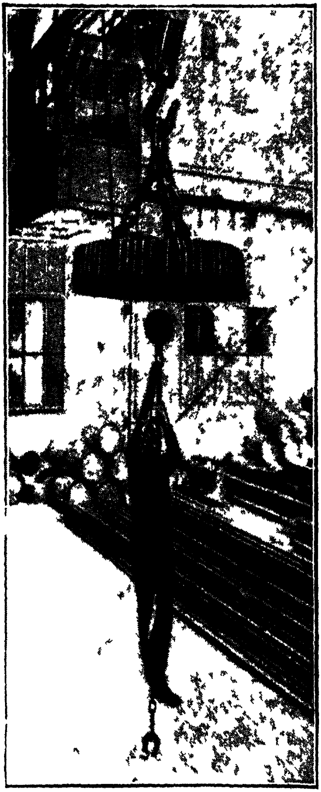


FIG. 49

ELECTRIC LIFTING MAGNET

(with Aluminium Coil) Showing Magnetic
Pull at a Distance

dissolved in benzol, turpentine or carbon bisulphide, and obtained insulation resistances of 102,000 megohms at 122 volts, and 9,000 megohms at 365 volts, with an insulation thickness of 0·2 mil. laid on a wire of 6,200 circ. mils. sectional area.

The essential factors in this development lay in the employment of aluminium oxide as the insulating covering, and the method of applying same to the conductor. But it is a widely known fact that the metal aluminium, on exposure to the atmosphere, becomes automatically coated with a thin transparent film of oxide which prevents further action, and which is instantaneously replaced when removed by abrasion or other means. This peculiar property accounts in great part for the difficulty of soldering the metal, and also for its freedom from corrosion and tarnish. It was not until 1905 that Hopfelt proved that this film would safely withstand a pressure of 0·5 volt, and conceived the idea of turning the principle to account in the development of a heat-resisting insulating material. Provided additional insulation was inserted between *layers* it was found to be a practical proposition to wind magnet and other coils direct with the bare aluminium wire, and a great number of coils in use at the present time are wound thus, and giving reliable service.

In practice, however, it is usual artificially to strengthen the oxide film to provide against various working contingencies, such as intense vibration, variations in temperature, etc., and this is carried out in a variety of ways. The wire may be run through a bath of sodium hydroxide solution in winding on to the coil, and the latter then dried out by the passage of a current through the windings. During the latter operation there is naturally a considerable amount of short circuit at the commencement, and a rheostat is therefore utilized to control the current until the temperature rises. The moisture is then driven off, and the insulation resistance quickly rises to a point at which short circuit ceases entirely, and a sufficiently stable insulation is obtained to give good results under working conditions. One of the better-known methods of reinforcing the natural oxide consists in the immersion of the coil in a bath composed of 100 parts saturated solution of borax, 60 parts ammonia, and 50 parts alcohol, maintained at a temperature of from 120–170° F. A current is passed for a few minutes, and the coil is then washed, dried and taped. Other methods include the heating of the wound coil of bare aluminium wire, and plunging whilst hot into a bath of cold oxidising liquid, which is drawn by the contraction of the air within the winding into intimate contact with the entire coil. As an alternative the coil may be immersed cold in a hot oxidising solution, and the whole allowed to cool. Running the oxidised wire through grease, insulating paint, etc., further protects the winding from damage, electrical or mechanical. The advantages claimed for such coils come under three main headings: (1) Saving weight of their equivalent in copper while occupying very much the same space; (2) the heat radiation from what practically amounts to a solid mass of metal is necessarily good and permits high current densities; (3) cotton and silk coverings commence to carbonise at about 175° F., enamels seldom withstand much above 250° F., while temperatures up to double these figures are said to improve rather than detract from the efficiency of the oxide insulation.

Incidentally, aluminium coils wound thus are generally cheaper, and this fact coupled with the good space factor obtained, has induced designers to apply the principle to *copper magnet coils.* Roewenthal, Berlin, accomplishes this by electrolytically depositing aluminium hydroxide on either an aluminium or copper wire, connected up as a cathode in a bath of aluminium-ammonium oxalate. Sufficient current is passed to cause violent decomposition of the double salt, and the resulting deposit is subsequently converted to the oxide by heating. A better treatment in the case of copper consists firstly in etching the surface by the passage of a current whilst immersed in a bath of sodium acetate containing a certain amount of free acetic acid. The wire is then immersed in a bath of aluminium acetate, to which a small quantity of nitrate of mercury has been added, and it is here that the deposit of aluminium hydroxide takes place. The wire should preferably be thoroughly cleaned in ammonia or benzol previous to the process, and on completion of the operations should be heated to dryness.

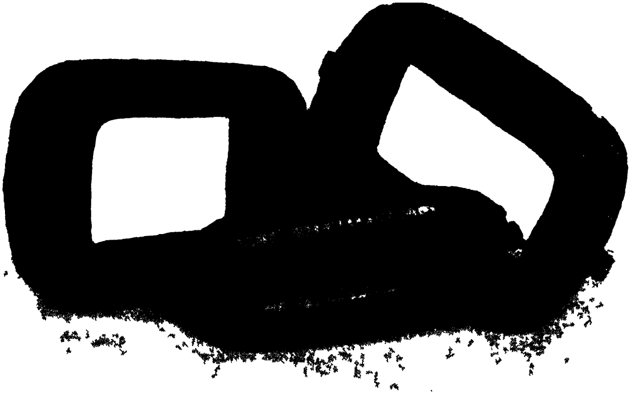


FIG. 50

MAIN AND INTERPOLE ALUMINIUM FIELD COILS

L. W. Chubb, of Pittsburg, has taken out patents covering the electrolytic deposition of aluminium oxide on conductors, the proposed bath consisting of ammonium borate or a solution of borax. It is impossible to make use of the natural oxide by depositing metallic aluminium on the copper, but where coils are of the edge-wound spiral type the single turns may be separated by a *thin layer of aluminium foil,* the oxide on which has been strengthened by passing through a bath of ammonium borate, and this method has been developed by the British Westinghouse Co., Ltd. A current is passed through the strip and bath during immersion, and the resulting insulation withstands high temperatures and forms a good heat-conducting medium.

In addition to the processes briefly outlined above, there are one or two excellent insulations of this class on the market, the preparation of which is kept a trade secret. At the present date development along these lines has by no means reached finality, and numbers of patents periodically appear which have yet to be tried under working conditions. Although reliable data is not easy to obtain, reports of the working of these aluminium coils in such trying extremes of temperature and mechanical stress as are afforded by traction motors, lifting magnets, etc., are sufficiently encouraging to warrant further investigation. The principle presents attractive features, and in view of the results recently claimed would certainly appear to offer possibilities of a practical nature.

As applied to the field coils of heavy traction motors, the idea has met with a large measure of success; apart from its technical advantages, it is stated that the weight saved by fitting these coils to a modern suburban train, having 4–240 horse-power motors, is equivalent to that of 15 passengers.

TABLE XII

ALUMINIUM FUSE WIRE

Fusing Current in Amperes.	Diameter		Fusing Current in Amperes	Diameter	
	Mm.	Ins.		Mm.	Ins.
1	·066	·0026	110	1·51	·0594
2	·104	·0041	120	1·60	·0630
3	·137	·0054	130	1·69	·0664
4	·165	·0065	140	1·77	·0698
5	·196	·0076	150	1·86	·0732
7·5	·251	·0099	160	1·94	·0763
10	·305	·0120	170	2·02	·0796
12·5	·354	·0139	180	2·10	·0826
15	·404	·0159	190	2·18	·0858
17·5	·442	·0174	200	2·25	·0886
20	·485	·0191	220	2·40	·0943
25	·559	·0220	240	2·54	·0999
30	·635	·0250	260	2·67	·105
35	·704	·0277	280	2·82	·111
40	·770	·0303	300	2·94	·116
45	·833	·0328	320	3·08	·121
50	·894	·0352	340	3·20	·126
60	1·01	·0397	360	3·33	·131
70	1·13	·0440	380	3·46	·136
80	1·22	·0481	400	3·56	·140
90	1·32	·0520	450	3·86	·152
100	1·42	·0558	500	4·14	·163

The above table has been calculated from the formula—

$$d = \frac{A^{\frac{2}{3}}}{15{\cdot}19} \text{ or } d' = \frac{A^{\frac{2}{3}}}{386{\cdot}1} \quad \text{(W. H. PREECE.)}$$

WHERE A = Fusing current in Amps.
d = Diam. in Mms.
d' = Diam. in Ins.

The preceding three chapters will serve to show the nature of the progress which has been made since 1855, when the first article ever made of aluminium—a baby rattle for the Prince Imperial—was exhibited at the Paris Exposition. Apart from the better-known applications of the metal, large consignments are absorbed into such widely contrasted fields as collector bows (which take current from the overhead lines on electric railway systems), and the shoes for race-horses, the lithographic " stone " used by printers, and the foil which has almost entirely superseded silver foil because of its non-tarnishing properties. There are myriads of minor applications in which the metal is beginning to play a more or less essential part, and, as indicated in this section, in many cases it is not so much the substitution of the metal for an existing material as the opening up of new vistas of industrial development, the limits of which are at present difficult to define.

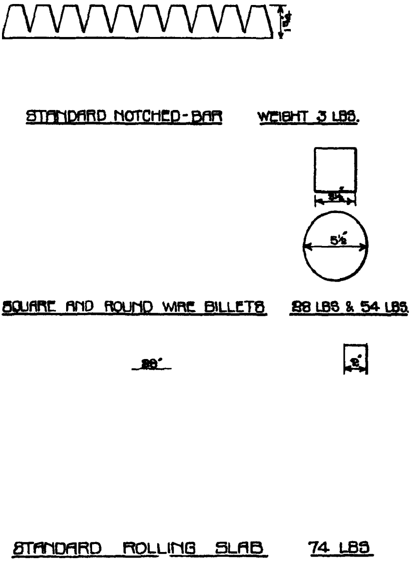
APPENDIX

A BRIEF NOTE ON MARKETING

IN a comparison with the older metals, the marketing of aluminium is much simplified by two features. Firstly, there is at present little or no "open market" in this commodity: all the big producers market their own metal, which is therefore not so liable to the violent and frequently disconcerting fluctuations in price associated with the metal market as a whole. And, secondly, all aluminium is "electrolytic aluminium," and although all electrolytic aluminium is not necessarily of one consistent level of purity, yet by dealing with reputable producers a purchaser can be assured of obtaining a pure metal direct, without costly assaying or further refining. The forms in which aluminium is placed on the market may be grouped under the headings of "Unmanufactured" and "Semi-manufactured" metal. In the former there are ingots and notched bars for export and casting purposes, slabs and blocks for rolling into sheet and strip, and wire-bars for rod, wire and strand. This section also includes such forms as granules for the treatment of crucible steel, and a great range of casting alloys to meet various needs, cast for convenience of customers into the notched bar form.

Into the second classification fall such forms as sheet, strip, rod and wire, and a comprehensive choice of extruded sections for beading, step-edging, collector bows, and kindred requirements. A notable example of an extruded section is seen in the radiator of the Lewis Gun.

Manufacturers of aluminium ware buy their sheet either in the form of circles, or in the form of strip with a "returning charge" on the scrap material returned to the producer. Provided the history of the metal is known, as it is in this case, there is little difficulty in disposing of aluminium scrap, but the former method would appear the more logically sound since it saves the freightage of the weight of scrap in both directions.



STANDARD NOTCHED-BAR WEIGHT 3 LBS.

SQUARE AND ROUND WIRE BILLETS 28 LBS & 54 LBS.

STANDARD ROLLING SLAB 74 LBS

FIG. 51

SOME STANDARD FORMS OF UNMANUFACTURED METAL

In the case of cable, bus-bar and rod for electrical work, "high purity, for electrical purposes" specified on the inquiry will ensure careful selection, so that the whole consignment may be of consistently high purity to meet the needs of maximum conductivity required in this branch.

In the home markets sales were formerly effected on a cash basis, but are now more generally 2½ per cent monthly, prices including delivery at purchaser's works. Export business is quoted c.i.f. (cost, insurance, freight) to enable a customer to see at a glance the liabilities he will have to meet, delivery being at a port agreed upon. Export terms are always nett cash against documents, unless by mutual arrangement to meet peculiar circumstances. Purchasers are advised to make a study of the current customs' tariffs of the country they desire to take delivery in: it is often possible to effect material economies by specifying some form of the metal assessable at a comparatively low rate.

An estimate of the world's production of aluminium and its average price is given herewith, dating from 1900 onwards. The figures are taken from a series of curves, drawn from data which has been issued at intervals over a number of years.

YEAR	World's Production in Long Tons	Average Cost of Ingot in pounds sterling
1900 . .	7,300	130
1901 . .	7,400	130
1902 . .	7,900	130
1903 . .	8,200	130
1904 . .	9,200	130–170
1905 . .	11,400	130–150
1906 . .	14,300	130–160
1907 . .	19,500	200–106
1908 . .	18,200	100–50
1909 . .	33,500	65
1910 . .	49,200	60
1911 . .	49,500	62
1912 . .	72,300	60
1913 . .	78,200	80
1914 . .	82,500	82
1915 . .	91,200	92
1916 . .	136,000	166
1917 . .	150,000	220
1918 . .	165,000	228
1919 . .	—	150

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